An examination of commodity derivative markets: efficiency, volatility and diversification benefits

by

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Abstract

This thesis comprises three papers which all examine commodity derivative markets and have a particular focus on commodity futures markets. The first paper examines market efficiency in metal, agricultural, financial and energy futures markets across different maturities. In the long-run, we found all markets to be efficient. And in the short-run, inefficiencies are found in the metal and energy future markets but not in the agricultural and financial markets. Moreover, results from a quantitative measure of short-run inefficiency indicate that all markets studied are at least 90% efficient along the futures curve for a 30-day forecast horizon. When the forecast horizon increases to 60-days, the efficiency measure drops to 50% in all the metal and energy futures markets, but not in the agricultural and financial markets. These findings indicate that the structure of markets and the forecast horizon are important factors to consider when assessing market efficiency.

The second paper analyses the diversification benefits brought into traditional stock portfolios by adding commodities such as WTI Crude Oil, Copper or Soya Bean futures. Adopting a commodity futures curves perspective, we found that commodities are still useful in portfolio diversification even after the recent increase in the correlation between returns of commodities and equities. Moreover, we found that investors would be better off using a constant-distant maturity futures contract as it has higher return accompanied with lower volatility in comparison to a short-maturity futures contract. The constant-distant maturity also brings more benefit than a traditional buy and hold long-maturity futures

contract does. Furthermore, we found the constant-distant maturity Copper futures to be the best among all the commodities that we studied regarding the diversification benefit during the financial turmoil period.

The third paper examines the determinants of volatility along WTI Crude Oil futures curves. We analyse the effect of inventory, trading volume, open interest and speculative activities on the volatility of futures with different maturities. We find that trading volume has a positive relationship with volatility and open interest has a negative relationship with volatility. The inventory is found to have a negative relationship with volatility of up to 6-month maturity; while a positive relationship emerges for futures contracts with 12 and 18-month maturity. Speculative activities are found to be partially responsible for the high volatility in the post-crisis period.

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Introduction

This thesis comprises three essays examining commodity derivative markets, with a particular focus on commodity futures markets. The importance of commodity futures contracts with regards to hedging and price discovery is well known to market participants. It is also widely known that the success of hedging and pricing depends on how efficient markets are. The Efficient Market Hypothesis (EMH) of Fama (1970) suggests that there are three form of market efficiency; strong form, semi-strong form and weak form efficiency. The strong form of market efficiency points out that all available both public and private information is reflected in prices. The semi-strong form efficiency indicates that all available public information is incorporated in current prices while weak form of efficiency specifies that all past price information is already incorporated in today's prices. In this context, if futures prices reflect all available information then they provide the best forecast of futures spot prices, in other words, futures price is assumed to be an unbiased estimator of future spot price in an efficient market (Garcia and Leuthold, 2004). In the first chapter of this thesis we examine the weak form of market efficiency in metal, agricultural, financial and energy futures markets.

Market efficiency implies that futures price and spot price have a cointegrating relationship indicating a long-run equilibrium. Moreover, the short-run market efficiency requires past price information to be not useful to predict future spot prices as all the available information should have been already incorporated in futures prices. This hypothesis has been heavily investigated in the literature from both long-run and short-run perspective. However, the results up to date are mixed as some studies found efficiency while others found inefficiency in the same markets. For example, Crowder and Hamed (1993) found a cointegrating relationship between futures and spot prices of WTI Crude Oil market and no evidence of risk premium indicating efficiency in this market. However, although Moosa and Al-Loughani (1994) found also a cointegrating relationship in the same market further analysis revealed that a time-varying risk premium exists which indicates futures price is not an unbiased estimator of future spot price. McKenzie and Holt (2002) found short-run inefficiencies and pricing biases in live cattle, hogs and corn futures while Aulton et al. (2007) found some inefficiency and biases in pig and potato markets. The findings in metal markets are also similar. While Moore and Callen (1995) cannot reject the unbiasedness hypothesis for copper futures traded at LME, Chowdhury (1991) and Beck (1994) reject the same hypothesis for the same market.

Moving on, Kawamoto and Hamori (2011) point out that if a futures price is an unbiased estimator of future spot price then a long-maturity futures price can been seen as the market expectation of a short-maturity futures price, where maturity is defined as the time remaining until expiration. They found that WTI Crude Oil futures market is efficient along yield curve from both long and short-run perspective. To the best of our knowledge theirs is the only study that analyses market efficiency within n-month maturity futures contracts as all the studies above use futures and spot prices. Following Kawamoto and Hamori (2011), our study analyses both long-run and short-run market efficiency as well as the degree of inefficiency in aluminium, copper, nickel, zinc, live cattle, USD/GBP and WTI Crude Oil futures markets using contracts with up to 8-month maturity.

We start our analysis from the long-run perspective that each pair of futures prices (0-1 month, 1-2 month, 2-3 month, …, 7-8 month maturity) have a cointegrating relationship. The results from Johansen cointegration analysis indicate that we cannot reject the existence of a cointegrating vector in all markets studied and among all maturities. We further examine the existence of a [1, -1] cointegrating vector and found that we cannot reject the market efficiency in the long-run in all commodities studied and among almost all maturities. The short-run market efficiency, the possibility that past price information could be used to forecast short-maturity futures prices, is examined using an ECM. The results indicate that there are inefficiencies in all metal futures and among all maturities, while exchange rate futures market is efficient among all maturities and live cattle is efficient among six maturities out of eight. Moreover, we found inefficiencies in WTI Crude Oil futures among all maturities but 3-4 month maturity. This result contradicts findings of Kawamoto and Hamori (2011) as they found short-run efficiency within all 8-month maturities. However, as Garcia and Leuthold (2004) point out the results of efficiency analysis depends on several aspects such as the methodology chosen and the time period.

Kellard et al. (1999) point out that concluding markets are efficient or not without giving any degree of efficiency does not provide much information for market participants. Following them, we next analyse the quantitative degree of short-run inefficiencies in these markets across different maturities. It is found that all maturities in all markets studied have around 90% efficiency from 30 days forecast horizon. The short-run inefficiency analysis from 60 days forecast period gives some interesting results. The efficiency measure in all metals and WTI crude oil futures market drops to around 50% but not for live cattle and USD/GBP contracts. Further analysis reveals that the inefficiency in these markets arises because the long-maturity futures price is substantially inferior predictor of the short-maturity futures price from 60 days forecast horizon but this is not true in live cattle or the exchange rate market. Furthermore, analysing the structure of these markets reveals some interesting results. The metal futures and the WTI Crude Oil futures have contracts listed every trading month while live cattle and USD/GBP have contracts listed every two months. The trading volume in these markets also reveals that the level of trading volume of an individual contract is at its highest in the last month before the expiration in metal and WTI crude oil futures, while it is at its highest level in the last 2 months in live cattle and exchange rate markets. This indicates that all available information is incorporated in futures prices every month in former markets while every two months in later ones when the rolling over takes place. These results indicate that forecast horizon and the structure of the futures markets should be taken into account when analysing market efficiency.

Our contribution to the literature in the first research chapter is that we are the first study to analyse market efficiency using contracts with up to 8-month maturity in Copper, Aluminium, Nickel, Zinc, Live Cattle and USD/GBP futures markets. Moreover, we are also the first study to analyse short-run inefficiency in relative terms across different maturities in these markets. Our findings give some interesting information to market participants. We show that rejecting market efficiency in the short-run does not mean that markets are not efficient at all, as in fact, all of the markets studied were efficient at least 90 %. The most important result is that the forecast horizon and the structure of the futures market are important factors that should be taken into account when analysing market efficiency.

In the second research chapter of this thesis we analyse the diversification benefits brought into traditional stock portfolios by adding energy, metal and agricultural futures contracts. The special features of commodities such as equity like returns, low correlations with traditional stocks and bonds, positive co-movement with inflation and a tendency to backwardation in the futures curve made them a profitable asset class to investors (Gorton and Rouwenhorst, 2006; Chong and Miffre, 2010; Buyuksahin et al., 2010). However, there have been some significant changes in the commodity markets over the last decade. Commodity prices soared significantly in 2003 after having low and moderately fluctuating prices for almost 30 years (Delatte and Lopez, 2013). For example, WTI Crude Oil spot prices rose to around 140 $/bbl. in 2008 from around 30 $/bbl. in 2003. This significant price increase in commodities often attributed to strong demand from emerging Asia, slow supply responses, bio-fuel policy changes, a depreciating US dollar and low interest rates (Silvennoinen and Thorp, 2013). Moreover, the financialization of commodity markets, which is believed to be the result of an excessive index investment in commodities as a form of financial speculation, also attributed to unwarranted increase in prices and volatilities (Masters 2008, 2009). For example, the total value of the funds invested in index-related commodity products have increased substantially to 200 Billion Dollars in 2008 from an estimated 15 Billion Dollars in 2003 (Tang and Xiong, 2012). All these significant developments in commodity markets have raised the question regarding whether diversification benefits still exist?

Many studies that analyse the diversification benefits of commodities before the 2008 financial crisis period conclude that there is a negative or very low correlation between returns of commodities and equities, hence investors would be better off using commodities in their portfolios (Erb and Harvey, 2006; Gorton and Rouwenhorst, 2006; Buyuksahin et al., 2010; Chong and Miffre, 2010). However, many recent studies found that there is an increased correlation between commodities and equities, and analysed the reasons behind this increase (Buyuksahin and Robe, 2014; Delatte and Lopez, 2013; Li and Zhang 2013; Bhardwaj and Dunsby, 2012; Silvennoinen and Thorp, 2013; Bicchetti and Maystre, 2012 and Tang and Xiong, 2012). Buyuksahin and Robe (2014) argued that increased hedge-fund participation in the market, especially those who trade both in equity and commodity markets caused this increasing trend. Silvennoinen and Thorp (2013) suggested that the increase in the VIX index was the reason. Bhardwaj and Dunsby (2012) argued that the correlation between stocks and commodities has a business cycle which is higher during period of economic weakness. Li and Zhang (2013) claimed that the recent financial crisis lifted the trend of correlation between stocks and commodities dramatically, which has a greater and wider trend-breaking impact than other financial crisis. Tang and Xiong (2012) studied increased correlation between commodities and found that prices of non-energy commodities become highly correlated to oil prices, especially those that are traded in a commodity index, arguing that this is the effect of financialization.

It important to note that Geman and Kharoubi (2008) argue that the choice of the maturity of futures contracts matters on the issue of portfolio enhancement as the futures curves of commodities are exposed to contango and backwardation. The market is said to be in backwardation when the price of a distant maturity futures contract is lower than a short maturity one and it is in contango otherwise. When the market is in backwardation, the price of the distant maturity futures contract is expected to rise at maturity to converge with the spot price. Hence, if an investor has a long position in the futures contract he/she would benefit from positive roll yield; while he/she would be exposed to negative roll yield when the market is in contango. Here the idea is to use constant maturity futures contracts, like the constant maturity notes that are used in interest rate markets, to reduce the exposure to the negative roll yield. The second chapter of this thesis therefore investigates the benefits of using constant maturity WTI Crude Oil, Copper and Soya Bean futures contracts in portfolio diversification. Specifically, we analyse the dependence structure, the benefits of using constant maturity futures contracts, and most importantly we examine the question that what happened to those benefits if there were any after the so called financialization, the dramatic increase in the correlation between returns of commodities and equities. To the best of our knowledge, Geman and Kharoubi (2008) is the only study that investigates the benefits of using constant maturity commodity futures and we extend their work in several ways.

We start our analysis by investigating the dependence structure between returns of five constant maturities of WTI Crude Oil, Copper and Soya Bean futures contracts and the returns of S&P 500 Index using dynamic conditional correlations. WTI Crude Oil and Copper have 1, 3, 5, 12 and 18-month constant maturity futures while Soya Bean has 1, 3, 5 and 11 month maturity futures. The results show that in fact, there is a dramatic increase in the correlations between return of each constant maturity futures and the S&P 500 Index during the 2008 financial crisis which tallies with the findings of recent literature. Further analysis reveal that this increasing trend in the correlations seems to have started in early 2000s, which supports the argument of Tang and Xiong (2012) that the financialization has started in early 2000s. However, our results indicate that there is not any substantial difference in the correlation patterns of short-maturity and long-maturity futures contracts with the S&P 500 Index in all three commodities studied unlike Geman and Khaorubi (2008).

Portfolios were constructed with different weights and using each commodity futures curves, the S&P 500 Index and the estimated dynamic conditional correlations. We analyse our results over the full sample and two sub-sample periods that covers before and after 2008 financial crisis. The results indicate that an investor would be better off using a constant long maturity futures contracts instead of a short-maturity one in pre-crisis period in all commodities studied and this supports the findings of Geman and Kharoubi (2008) for WTI Crude Oil futures contracts. However, these benefits seem to have vanished for both WTI Crude Oil and Soya Bean futures contracts but surprisingly not for Copper futures in the post-crisis period. In fact, the diversification benefit of using short or long-maturity constant futures seem to vanished for WTI Crude Oil in post-crisis period as an investor would be better off investing only in the S&P 500 Index.

Finally, we use traditionally compiled long-maturity futures contracts in portfolio construction in order to compare the results with the long-maturity constant alternative. Our findings indicate that an investor would be better off using a constant long-maturity futures contract instead of a traditional long-maturity futures contracts in almost all commodities studied in both pre-and post-crisis period. The exception is Soya bean in post-crisis period. Moreover, our results indicate that the benefits of using constant long-maturity futures contracts come from the fact that they have lower volatility and higher return than their short-maturity counterparts not because of the difference in their dependence structure with S&P 500 Index.

Our contribution to the literature in the second chapter is that we are the first to analyse the benefits of using Copper and Soya Bean futures curves in portfolio diversification as well as to study the effects of the 2008 financial crisis on the diversification benefits of using WTI Crude Oil, Copper and Soya Bean futures curves. Our results indicate that investors would still be better off using commodity futures contracts in their portfolios even though the correlations between returns of commodities and equities have increased recently. However, the commodities should be chosen carefully as we show that Copper and Soya Bean futures are useful in portfolio diversification even after financial crisis but not WTI Crude Oil. Our most important finding is that investors would be better off using a long constant maturity Copper futures contract instead of a traditional long-maturity or short-maturity futures contract as they would enjoy a higher return accompanied with lower volatility even in the time of financial turmoil.

In the third research chapter of this thesis we examine price volatility along WTI Crude Oil futures curves using five constant maturity futures contract series. As mentioned above there have been some significant changes in the commodity markets over the last decade. Understanding volatility as well as the price dynamics in commodity markets is important to many market participants from hedgers to traders. For example, hedging ratios are adjusted based on the volatility of futures contracts. The optimal margins on futures contract trading are set by the volatility of these contracts; an increase in volatility would cause an increase in margin calls. Speculators take positions in futures markets based on their expectation of price variability; the greater the volatility the greater the profits. Moreover, the futures price volatility is a vital input in option pricing and high volatility would increase price of an option.

The Maturity Effect hypothesis of Samuelson (1965) argues that the price volatility of futures contracts increases with time to maturity; a contract's volatility increases with approaching to expiration. This hypothesis has been heavily investigated in the literature and findings to date are mixed and vary with markets. For example, Milonas (1986) and Galloway and Kolb (1996) find supporting evidence for maturity effect in agricultural futures markets; while Anderson et al. (1985) and Kenyon et al. (1987) find that seasonal effects are more prominent to explain volatility than maturity effect in the same markets. Moreover, Bessembinder et al. (1996) also find supporting evidence in agricultural markets and crude oil but not financial markets. Grammatikos and Saunders (1986) fail to find evidence in the currency markets while Barnhill et al. (1987) find strong evidence in Treasury bond futures markets. Furthermore, some studies found that trading volume and volatility have a positive relationship while open interest has a negative one and they dominate the maturity effect. (Ripple and Moosa, 2009; Herbert, 1995; Serletis, 1992; Bessembinder and Sequin, 1993).

The theory of storage of Kaldor (1939) and Working (1948, 1949) argues that inventory and volatility of spot prices have a negative relationship, and volatility of spot prices are higher than volatility of futures prices during terms of scarcity, which is also heavily investigated in the literature. Symeonidis et al. (2012), Geman and Nguyen (2005), Geman and Ohana (2009) and Geman and Smith (2013) found supporting evidence of this hypothesis. Moreover, Routheldge et al. (2000) found that conditional violations to Samuelson hypothesis occur at short horizons when inventory is sufficiently high; the price volatility of forward contracts increases with maturity. Furthermore, some of the studies analysed the effect of speculation on volatility especially after the testimony of Michael W. Masters (Masters, 2008, 2009) accusing speculators for the price increase and high volatility in the commodity markets. However, these studies failed to find any evidence that speculator behaviours increased the volatility in the commodity markets (Manera et al., 2014; Aulerich et al. 2013).

In the third research chapter of this thesis we therefore analyse the effect of inventory, trading volume, open interest and market share of speculation activities on the volatility of constant maturity WTI Crude Oil futures contracts and to the best of our knowledge we are the first to study the aggregate effect of these variables as well as to use constant maturity futures series. We start our analysis by estimating the volatilities in each constant maturity series; 1, 3, 6, 12 and 18-month using a GARCH model. Our results confirm the findings of earlier literature that whilst trading volume has a positive effect on volatility, open interest has a negative effect in all the maturities studied. The findings from inventory and market share of speculators variables are even more interesting. We found that the inventory variable and volatility has a negative relationship up to a 6- month maturity but this relationship is reversed at the 12 and 18-month maturity. In fact, the coefficient of inventory variable in 18-month maturity is almost as high as the coefficient in 1-month maturity with an opposite sign and significance. Moreover, it is found that the speculation variable is negative and significant in full period in all maturities studied. However, further analysis reveals that whilst the speculation variable and volatility have a negative relationship in pre-crisis period, it reverses to be positive in the post-crisis period in all maturities studied. Our findings are also confirmed through rolling and recursive regressions. Moreover these findings are robust even when we use different volatility estimator (high-low volatility estimator of Parkinson (1980)) and speculation variable (Working T Index).

Overall our contribution to the literature in the third research chapter is that we are the first study to analyse the determinants of volatility using constant maturity WTI Crude Oil futures as well as to examine the change in the relationship between possible explanatory variables and volatility in both a full, and pre and post- financial crisis period. We are also first to analyse the aggregate effect of trading volume, open interest, inventory and speculative activities on the volatility of commodity futures curves. Our findings are quite intriguing. The relationship between volatility and inventory variable being negative in 1-month maturity and positive in 18-month maturity is an important aspect for market participants. For example, this indicates that high inventory would decrease the volatility in short maturity futures while it increases in long-maturity futures. If an investor would be aware of that information, then they would increase their cash holdings as the margin calls would be higher or they could avoid using long-maturity futures at that time after all. Moreover, our results indicate that in fact it was partly speculative activities that caused the high volatility in WTI Crude Oil futures markets.

Chapter 1

Market efficiency among futures with differing maturities: evidence from metal, agricultural, energy and financial markets

1.1 Introduction

Futures markets' value comes from their ability to forecast cash prices at a specified future date and hence allow agents to alleviate welfare losses due to volatility of trading in a given commodity. If the futures markets are efficient, then agents would be able to alleviate their potential losses by using appropriate hedging instruments. However, if the futures markets are not efficient then agents will have to face an extra cost caused by price volatility in the markets. Here, Efficient Market Hypothesis (EMH) of Fama (1970) indicates that the futures price is an unbiased predictor of corresponding spot price assuming the rationality and risk neutrality of market participants in an efficient market. Thus, testing for market efficiency provides useful information to market participants.

Market efficiency in commodity futures has been heavily investigated in the literature. If market efficiency hypothesis holds then it is assumed that expected value of spot prices should be equal to futures price. Under the efficient market hypothesis and the assumption that market participants are not necessarily risk neutral most of the researchers use the equation below to analyse market efficiency between spot and futures prices;

$$S_{t+1} = \alpha + \beta F_t + u_{t+1} \quad (1.1)$$

Here, S_{t+1} denotes the spot price at time (t+1), F_t is the price of the futures contract at time t and u_{t+1} denotes the risk premium and is assumed to be stationary. If both spot and futures prices are non-stationary processes then a co-integrating relation with a co-integrating vector of [1,-1] should exist for market efficiency purposes which indicates that the deviation from the equilibrium is incorporated into the price information and the magnitude between spot and futures prices will not drift apart. For example, Crowder and Hamed (1993) examined the market efficiency in WTI (West Texas Intermediate) market between futures and spot prices, and obtained results that supporting the efficiency in this market while Moosa and Al-Loughani (1994) found that the restrictions on co-integrating vector do not exist in the same market. Moreover, Aulton et al. (1997) studied market efficiency in agricultural markets and found mixed results; efficiency in wheat market and inefficiency in potatoes market. McKenzie and Holt (2002) found efficiency in the long-run while inefficiencies in the short-run in live cattle, hogs and corn futures market. All of these studies above and almost all of the literature used futures and spot prices to analyse market efficiency in commodity futures markets.

Building on the work above, Kawamoto and Hamori (2011) argue that if the futures price is the market expectation of spot price, then a long maturity futures price can be seen as the market expectation of a short-maturity futures price, where the maturity is defined as the time remaining until expiration. They indicated that a futures market should also be examined among their different maturity futures prices for market efficiency purposes as there are contracts with different maturities traded in the market. Moreover, they argue that testing efficiency among futures with differing maturities increases the power of efficiency tests among futures and spot prices. The analysis is done by examining the equation below[1];

$$F_{t+1}^{(s-1)} = \alpha + \beta F_t^{(s)} + u_{t+1} \quad (1.2)$$

Here, $F_{t+1}^{(s-1)}$ is the price of (s-1) month maturity futures contract at time (t+1), $F_t^{(s)}$ is the price of s month maturity futures contract at time t and u_{t+1} is the risk premium. In this study we extend the work of Kawamoto and Hamori (2011) in three ways. First, we study the market efficiency among futures with differing maturities in metal (aluminium, copper, nickel and zinc), agricultural (live cattle), financial (GBP/USD exchange rate) as well as energy (WTI Crude Oil) futures markets to examine whether it holds in these markets. Secondly, our data period extends theirs and we are able to compare the results of WTI crude oil futures markets from a longer horizon. Lastly but most importantly, we use a relative degree of efficiency methodology to examine the quantitative degree of inefficiency in these markets among different maturities; which gives some interesting results.

Our results indicate that there is a co-integration relationship in all commodities studied among all maturity pairs. We also found that the existence of a co-integrating vector of [1,-1] differs among maturities although it exists in all commodities studied. This indicates that the long-run market efficiency condition holds in all commodities and almost among all maturities. However, the short-run efficiency analysis indicated interesting results. We found that the past price information is useful to predict short-maturity futures prices in all commodities but live cattle and exchange rate market. In the live cattle and

[1] See Kawamato and Hamori (2011) for the derivation of the equation.

GBP/USD exchange rate futures market we cannot reject the null hypothesis of market efficiency in the short-run almost among all maturities while it is rejected almost among all maturities in all other markets studied.

Moreover, analysing markets as efficient or not efficient without giving any degree of efficiency does not provide much information for market participants as Kellard et al. (1999) argued. Hence, we examine relative inefficiency; a quantitative degree of information about short-run market efficiency and the results are interesting. We found that all the markets studied present a relative efficiency of 90% among all maturities from a 30 days forecasting horizon although we rejected short-run efficiency in most of the markets studied. This indicates that concluding a market is inefficient might be misleading. Moreover, increasing forecast horizon to 60 days gives interesting results. We found that the relative efficiency measures drop to 50% in all markets but live cattle and GBP/USD exchange rate. The results indicate that most of the inefficiency in 60 days forecasting horizon comes from the inability of long-maturity futures price to predict short maturity futures price. Furthermore, the results indicate that the forecasting horizon is an important factor in determining the degree of short-run inefficiency.

The remainder of the chapter is organized as follows. The next section presents the literature on market efficiency and unbiasedness. Section 1.3 describes the data and the methodology used to analyse efficiency in metal, agricultural, financial and energy futures markets among differing maturities. Section 1.4 discusses the empirical findings. A conclusion is given in final section.

1.2 Literature

There have been many studies of market efficiency of financial and commodity futures markets in the literature since Fama's (1970) Efficent Market Hypothesis (EMH). Fama (1970) argued that there are three types of market efficiency; weak-form, semi-strong form and strong-form. The weak-form market efficiency is described as futures price is an unbiased predictor of spot price or in other words futures price reflects all available past price information. For example, Crowder and Hamed (1993) analysed WTI crude oil futures market traded on NYMEX for the period between 1983 and 1990. They argued that existence of a risk premium does not imply inefficiency of a market, and found a co-integrating relationship between spot and futures price, and no evidence of risk premium. Moosa and Al-Loughani (1994) analysed same market for the period between 1986 and 1990. They also found a co-integrating relationship, however in further investigation they concluded that the futures price is not an unbiased estimator of spot price; in other words futures price does not efficiently estimate the spot price and a time varying risk premium. Mamatzakis and Remoundos (2011) examined existence of a co-integrating relationship between spot and futures prices in Brent crude oil market from 1990 to 2009. They used a threshold VECM to be able to evaluate the degree and dynamics of transaction costs coming from various market imperfections. They argued that the tests in the literature fail to account for possible structural breaks in energy price data and hence they investigated the degree of integration of oil market in terms of threshold effects and adjustment costs. They found spot and futures prices are co-integrated, and that market follows a gradual integration path and a significant threshold exists. Moreover, they argued that the adjustment costs are present in the error correction and should not be ignored.

McKenzie and Holt (2002) studied market efficiency and unbiasedness in agricultural commodity futures markets using live cattle, hogs, corn and soybean meal spot and futures prices traded in CBT and CME[2] for the period between 1959 and 2000. They used cointegration and error correction models with GQARCH-in-mean processes and found that each market is efficient in the long-run but found short-run inefficiencies and pricing biases in live cattle, hogs and corn futures. Moreover, they found short-run time varying risk premiums in live cattle and hogs futures market. Aulton et al. (1997) studied market efficiency in agricultural futures markets traded in the UK using three commodities; wheat, pig meat and potatoes. They argued that much of studies in terms of agricultural commodities are US based and hence their study based on efficiency of the UK agricultural commodities. They used a cointegration based approach to test market efficiency for the period between 1980 and 1993. They used four different price series; spot price, one and two months advanced futures price, and future prices in the first week of delivery month. Their findings differs, for example, they found efficiency and unbiasedness in wheat market, some inefficiency in pig meat market and some inefficiency and bias in potatoes market. They argued that the inefficiency in pig meat and potatoes market due to serial correlation in the price series which indicates that futures price do not include all the information to inform spot prices.

Some of the studies that analysed market efficiency in metal futures are Canarella and Pollard (1986), Gross (1988), Sephton and Cochrane (1990, 1991), Chowdhurdy (1991). For example, Canarella and Pollard (1986) examines market efficiency of copper, lead, tin and zinc futures traded on LME for the period between 1975 and 1983. They found that futures price is an unbiased estimator of spot price using three different estimation methods. Gross (1988) analysed aluminium and copper futures markets traded on LME and found that EMH is not rejected for the copper futures market but not aluminium based on the mean square error correction. However, Sephton and Cochrane

[2] CBT: Chicago Board of Trade and CME: Chicago Mercantile Exchange.

(1990, 1991) also examined six metal futures traded on LME from 1976 to 1985 and found that the unbiasedness hypothesis is rejected for copper futures and the LME market is not efficient.

Moreover, Kellard et al. (1999) analysed market efficiency in six different futures markets; soybeans, live cattle, live hogs, gasoil, Brent crude oil and Deutsch Mark/Dollar exchange rate. They argued that the conflicting findings of efficiency/inefficiency in the literature come from the difference in time periods and methodologies that are used for analysis and no assessment of degree of efficiency is studied. They found that all the markets studied have a co-integrating relationship. Moreover, there are short-run efficiencies in these markets and in exact terms they found soybean market to be efficient 100 per cent while 1% inefficiency in gasoil, 4% inefficiency in DM/$, 7 % inefficiency in live hogs, 12% in Brent crude oil and 47% inefficiency in live cattle market within 28 days forecast horizon. Coakley et al. (2011) used daily prices of 14 commodities and 3 financial assets between 1990 and 2009 to investigate the impact of the time series properties of the future-spot basis and the cost of carry on forward market unbiasedness. They argued that the literature has contradictory results on market efficiency an hence, this study extends the literature by investigating whether the commodity basis exhibits a fractional order of integration and whether allowing for the presence of structural breaks reveals spurious long memory. It is found that 16 assets in the study have long memory and structural break which implies that cost of carry has long memory. Moreover, they argued that these findings indicate existence of long memory in the forecast error which is inconsistent with unbiasedness.

Furthermore, some other studies investigated the impact of public information and macroeconomic news on the commodity futures markets; Garcia et al. (1997) and Elder et al. (2012). Garcia et al. (1997) examined the value of US Department of Agriculture

(USDA) corn and soybean production forecasts on participants of the market. They used USDA and private crop forecasts data from 1971 to 1992, and three tests of informational value are used; ‘i) a relative forecast accuracy test, ii) a price reaction test and iii) a willingness to pay test’. They argued that USDA forecasts significantly affect the corn and soybean futures price according to price reaction test, and found that people are willing to pay for these forecasts which help them to have correct positions in the market. Elder et al. (2012) analysed the impact of macroeconomic news on the metal futures market. The intra-day data for the period of 2002 to 2008 was used for three commodity futures; gold, silver and copper. They examined the intensity, direction and speed of impact of US macroeconomic news on the return, volatility and trading volume of these three contracts. They found that the impact of news on three commodities is strong and instantaneous. Moreover, they argued that their findings show that the effect of macroeconomic news dissipates in about 60 minutes of the news release and market activity variables are definitely affected by some of the announcements. Moreover, they blamed the low frequency of measurement of the data in the literature for not being able to find impacts of news on commodity futures market.

Last but not least, while all of the studies above analysed market efficiency using spot and futures prices Kawamaro and Hamori (2011) argued that there are contracts with differing maturities traded in the market and hence efficiency between those contracts is also important to be able to conclude complete efficiency of a market. They argued that as futures price is an unbiased predictor of spot price then a long-maturity futures price can be seen as an unbiased predictor of a short-maturity futures price in some futures time, where the maturity is described as the time remaining until contract expiration. They studied WTI crude oil futures market for the period between 1991 and 2008 using up to 8-month maturity futures contracts. They found that WTI futures market is consistently efficient within the 8-month maturity and consistently efficient and unbiased within 2-month maturity in both long-run and short-run.

1.3 Data and methodology

1.3.1 Data

The data used in this study is collected from DataStream according to availability of the data for aluminium, copper, nickel, zinc, live cattle, WTI crude oil and GBP/USD exchange rate futures up to 8-month maturity to be able to analyse market efficiency in metal, agricultural, energy and financial futures markets. The time period for the monthly data series are as follow; metal futures (aluminium, copper, nickel and zinc) from 1994 to 2011 traded on LME (London Metal Exchange), live cattle from 1980 to 2011 and GBP/USD exchange rate from 1975 to 2011 traded on CME (Chicago Mercantile Exchange), and WTI crude oil from 1991 to 2011 traded on NYMEX (New York Mercantile Exchange). The price series for metal futures are in US Dollars per tonne, live cattle futures are cents per pound, GBP/USD exchange rate futures are US Dollars per British Pound and WTI Crude Oil futures are US Dollars per barrel. Each of these commodities has nine time series with different maturities, which are defined as 0-month, 1-month, 2-month, 3-month, 4-month, 5-month, 6-month, 7-month and 8-month maturity futures contracts. The zero-month maturity futures price is the prompt-month futures traded on the last trading day of every month, while 8-month maturity futures price is the price of the same contract that has 8 months to expiration. In general form, the (s+1)th month's futures traded on the last trading day of every month are futures with s months up to maturity. Hence, the settlement price of the (s+1)th contract traded on the last trading day of every month, with one month interval to prevent informational overlap, are collected to develop the time series. Thus, it should be noted that the expiration date for all series (0-month, 1-month,…, 8-month) in a given market for a specific contract are same.

The price series are created as follow; the price of a contract on the last trading day is the 0-month maturity series, price of the same contract traded a month before the last trading day is the 1-month maturity series and hence price of the same contract traded eight months before the last trading day is the 8-month maturity series. It should be noted that for a specific contract price series are the prices of the same contract collected historically. Hence, price series from 0-month to 8-month does not show the forward curves but the prices of the same contract over a period of time. The price series are shown in Figure 1.1 for all commodities. Numbers of observations for each series are given in Table 1.1 and shows that metal futures have 213, live cattle has 192, GBP/USD exchange rate futures has 140 and WTI Crude Oil futures has 264 observations for each maturity time series. Table 1.2 represents the Trading Volume of each commodity across different maturities. Trading volume of a specific contract, here it is December 2011 contract, is taken on the last trading day, a month before the last trading day and two months before the last trading day as well as the total trading volumes during the last month of trading and two months before expiration.

1.3.2 Unit Root Analysis

All of futures contracts' time series in this study are examined in their natural logarithmic forms. When a series y_t needs to be differenced d times to make it stationary then this series is said to be integrated of order d $(y_t \sim I(d))$, and if it has to be differenced once in order to make it stationary, then this series is called to be I(1) in other terms to have a unit root. The stationarity of series is important in regression analysis as the use of non-stationary time series would lead to spurious regressions. For example, in general if two unrelated variables regressed one another the significance of the coefficients would be expected to be very low as well as the R^2 of the regression. However, if these two variables are trending over time the regression results would be significant although they are unrelated and so the results would be meaningless and misleading. Hence, all the series are analysed for non-stationarity using both ADF (Augmented Dickey Fuller) and KPSS (Kwiatkowski, Phillips, Schmidt and Shin) tests. SCI (Schwarz information criterion) is used to select the optimal lag length to use in ADF test, and Barrett kernel is used to choose the optimal bandwidth in KPSS test. Both tests are used in order to have more accurate results as they have opposite null hypothesis; it is that series has a unit root in ADF while series are stationary in KPSS and hence one should be able to reject ADF test while do not reject KPSS test to be able to conclude that the series examined is stationary.

1.3.3 Johansen cointegration and cointegrating vectors

The efficiency of a market in the long-run requires that the same information to be reflected for both long-maturity ($F_t^{(s)}$) and short-maturity futures prices ($F_{t+1}^{(s-1)}$) and so that they will not drift too far from each other. Thus, if two time series are unit root processes then a co-integrating relationship must exist between them so as not to drift apart from each other. For this purposes Johansen method of reduced rank regression based on VARs is used for cointegration analysis and the existence of a [1,-1] co-integrating vector is examined. This technique specifies a VECM (Vector Error Correction Model) of the g-variable VAR for a time series vector y_t as;

$$\Delta y_t = \Pi y_{t-k} + \Gamma_1 \Delta y_{t-1} + \Gamma_2 \Delta y_{t-2} + \cdots + \Gamma_{k-1} \Delta y_{t-(k-1)} + u_t \qquad (1.3)$$

where k is sufficiently large so that u_t is a vector white noise. This test centres on an examination of the rank of Π, the gxg parameter matrix of the lagged levels of variables. The optimal lag length k was chosen by SCI. The Π is a long-run coefficient matrix, and Πy_{t-k} has to be stationary for u_t to be stationary if y_t is a vector of I (1) variables. There are two different test statistics for cointegration analysis; trace (λ_{trace}) and max-eigenvalue (λ_{max}). The null hypothesis of the trace statistics is that the number of co-integrating vectors equals or less than r, where r is the rank, to the alternative hypothesis that there is more than r. On the other hand, the max-eigenvalue statistics has the null hypothesis that number of co-integrating vectors equals r against to the alternative $r + 1$. Moreover, the zero rank (r) of Π implies no cointegrating relationship between series and which indicates there are no linear combinations of y_t, that are not I (1), while the full rank (r) of Π states that the series are stationary in levels.

1.3.4 Short-run efficiency

Short-run market efficiency analysis in our study for all commodities is done using an Error Correction Model (ECM) developed by Beck (1994); the possibility that past price information could be used to improve the forecast accuracy is examined, assuming constant risk premiums. The lag selection in our analysis is based on general-to-specific methodology following Kellard et al. (1999), we start with 10 lags and reduce it according to significance of lags while preserving symmetry on lag length of short and long maturity futures. This procedure removes all evidence of residual serial correlation. The model is as below;

$$\Delta F_{t+1}^{(s-1)} = c - p\, u_t + b_0\, \Delta F_t^s + \sum_{i=1}^{m} a_i\, \Delta F_{t+1-i}^{(s-1)} + \sum_{j=1}^{n} b_j\, \Delta F_{t-j}^{(s)} + \varepsilon_{t+1} \quad (1.4)$$

here;

$$u_t = F_t^{(s-1)} - \alpha - \beta F_{t-1}^{(s)} \tag{1.5}$$

$$\Delta F_{t+1}^{(s-1)} = F_{t+1}^{(s-1)} - F_t^{(s-1)} \tag{1.6}$$

$$\Delta F_t^{s} = F_t^{(s)} - F_{t-1}^{(s)} \tag{1.7}$$

Beck (1994) indicates that the cointegration implies $p > 0$ because short-maturity futures price changes respond to the deviations from the long-run equilibrium in the equation. Moreover, the coefficient b_0 (which corresponds to the long-maturity futures price changes in the equation) should be non-zero because all available new information, concerning short-maturity futures price changes, to be reflected immediately into long-maturity futures price. Furthermore, coefficients a_i (lagged short-maturity futures price changes) and b_j (lagged long-maturity futures price changes) should be zero as the past price information has been already incorporated into the long-maturity futures price. Lastly, the condition that $p = 1,\ p\beta = b_0,\ a_i = b_j = 0$ should be established, otherwise past price information could be used to improve the forecast accuracy which violated the market efficiency.

1.3.5 Short-run Inefficiency

Kellard et al. (1999) argues that analysing the markets as efficient or inefficient without a degree of efficiency do not allow a quantitative comparison of the functioning of the different futures markets considering the fact that the cost of hedging rises as market becomes inefficient. Hence, a quantitative measure of inefficiency developed by Kellard et al. (1999) is used in our analysis to examine the degree of inefficiency in these markets. The short-run inefficiency measure defined as below;

$$\varphi_c = \frac{(n-2k-2)^{-1}\sum_{t=1}^{n}\hat{\varepsilon}_t^2}{(n-1)^{-1}\sum_{t=1}^{n}[\left(f_t^{(s-1)} - f_{t-1}^{(s)}\right) - (\overline{f_t^{(s-1)} - f_{t-1}^{(s)}})]^2} \tag{1.8}$$

Here the numerator is the estimated error variance of the short-run OLS regression in Equation (1.4), whereas the denominator is the sample variance of the forecast error, based on the long maturity futures price, corrected for degrees of freedom. A ratio of 1 that is estimated by the equation above would indicate complete efficiency, and the quantities varying between 0 and 1 degree of inefficiency. Moreover, two adjusted coefficients of determination-like measures are calculated to be able to address the issue of absolute predictor quality which are;

$$\bar{R}_1^2 = 1 - \frac{(n-2k-2)^{-1}\sum_{t=1}^{n}\hat{\varepsilon}_t^2}{(n-1)^{-1}\sum_{t=1}^{n}[\left(f_t^{(s-1)} - f_{t-1}^{(s-1)}\right) - (\overline{f_t^{(s-1)} - f_{t-1}^{(s-1)}})]^2} \tag{1.9}$$

$$\bar{R}_2^2 = 1 - \frac{(n-1)^{-1}\sum_{t=1}^{n}[\left(f_t^{(s-1)} - f_{t-1}^{(s)}\right) - (\overline{f_t^{(s-1)} - f_{t-1}^{(s)}})]^2}{(n-1)^{-1}\sum_{t=1}^{n}[\left(f_t^{(s-1)} - f_{t-1}^{(s-1)}\right) - (\overline{f_t^{(s-1)} - f_{t-1}^{(s-1)}})]^2} \tag{1.10}$$

These two measures above compares forecasts based on the short-run OLS regression (ECM) and the long-maturity futures price as a predictor with prediction from the last available short-maturity futures price, respectively. Hence the relative efficiency measure φ_c can also be calculated by;

$$\varphi_c = \frac{1-\bar{R}_1^2}{1-\bar{R}_2^2} \tag{1.11}$$

1.4 Empirical findings

First of all, the results for stationarity of each series of all commodities studied are given in Figure 1.2a to 1.2g. In each Graph part (A) and (B) give the result of ADF tests on having a unit root while part (C) and (D) give the results from KPSS tests of stationarity using raw series. It is found that for all commodities and maturities we cannot reject the null hypothesis of having a unit root with ADF tests, while we reject null hypothesis of stationarity with KPSS tests. Part (E) and (F) gives result for same hypothesis using series that are differenced once, and it is found that we cannot reject stationarity from both ADF and KPSS tests. These results show that our time series have a unit root which is in favour of the literature.

Market efficiency in the long-run among different maturities in all commodities studied is analysed using the cointegration relationship and the cointegrating vectors in Equation (1.2). The cointegration relationship and the existence of a [1, -1] cointegrating vector among all maturities is carried out by using Johansen method of reduced rank regression based on VAR in Equation (1.3). Results of trace and max-Eigenvalue tests on cointegration relationship for all commodities are given in Table 1.3 and test results for existence of a [1, -1] cointegrating relationship is given in Table 1.4. It is found that we reject the null hypothesis of no cointegration while the null hypothesis of existence of one cointegrating relationship cannot be rejected in all commodities among all maturities. While we found that a cointegration relationship exists among all commodities and all maturities studied, Table 1.3 shows that the existence of cointegrating vectors are rejected in some commodities. For example, we reject the existence of [1, -1] cointegrating vectors between 2-3, 4-5 and 4-5 month maturities in WTI crude oil futures while we cannot reject for the rest of maturities at 5% significance. This result is in fact in contrast to the findings of Kawamoto and Hamori (2011) as they found that cointegrating vectors exist among all maturities in WTI crude oil futures market. Overall, the cointegration relationship exists among all maturities in all commodities while the existence of cointegrating vectors is rejected among some maturities.

The dependency of short-maturity futures prices on past price information, in other words short run market efficiency, is investigated using Beck (1994) ECM in Equation (1.4). The results are given in Table 1.5a through Table 1.5g for aluminium, copper, nickel, zinc, live cattle, GBP/USD exchange rate and WTI crude oil futures, respectively. Results show that in all markets studied both lagged short-maturity and long maturity futures prices are significant indicating that past price information can be used to predict the dynamics in short-maturity futures prices. However, it is found that in some maturities the lagged short and long-maturity futures prices are not significant at all and hence dropped out of regression such as; 4-5 month maturity futures in copper and zinc market, 6-7 month maturity futures in nickel market, 5-6 month maturity in live cattle and 2-3 and 5-6 month maturity in exchange rate market. Moreover, we found that $p > 0$ and significant condition holds in all commodities among all maturities, which indicates that a cointegration relationship exists where short-maturity futures price changes respond to deviations from the long run equilibrium in Equation (1.2). Furthermore, another condition of short run market efficiency that $b_0 \neq 0$, which corresponds to long-maturity futures price changes, is found to be hold among all maturities in all commodities. It is interesting to see that coefficient of b_0 is higher and more significant in live cattle and GBP/USD exchange rate market as shown in Table 1.5e and Table 1.5f, respectively. Last but not least, the last row of each table gives the result of Wald test on the null hypothesis that $p = 1$, $p\beta = b_0$, $a_i = b_j = 0$ which is a condition indicating overall short-run market efficiency. It is found that we reject the null hypothesis in all markets almost among all maturities but live cattle and GBP/USD exchange rate market. This indicates that all the markets studied have short-run inefficiencies but live cattle (apart from 2-3 and 6-7 month maturity) and exchange rate as shown in Table 1.5e and 1.5f, respectively. Although the lagged short-maturity and long-maturity price changes are significant in these two markets they are not significant enough to reject the null hypothesis of overall short-run market efficiency as the coefficient of b_0 (long maturity futures price changes) is highly significant, which indicates that all available new information is already reflected in long-maturity futures prices.

Kellard et al. (1999) points out analysing markets as only efficient and not efficient without giving any degree of inefficiency does not indicate how badly or well the markets are functioning. The degree of inefficiency is potentially a considerable value as the cost of hedging rises when the markets become less efficient, and hence there exist a relationship between costs, and inefficiency and futures trading (Stein, 1986). In this study, the inefficiency measure is based upon the relative ability of the long-maturity futures price to forecast subsequent short-maturity futures price. The relevant comparative forecast of short-maturity futures price is provided by fitted Equation (1.8). Based on Equation (1.4) inefficiency arises because long-maturity futures price is a poor predictor of short-maturity future price and also additional information is provided by other lagged variables beyond that incorporated in the long-maturity futures price.

The degree of inefficiency in our study is analysed among all maturities and all commodities from both a 30 days and 60 days forecast horizon and the results are given in Table 1.6 and 1.7, respectively. It is found that all six commodities and one financial futures market we analysed have an efficiency measure of above 90% among most of the maturities from a 30 days forecasting horizon. Here, a reasonable estimate of degree of inefficiency is provided by the efficiency measure φ_c without relying on pretesting.

However, it should be noted that the relative efficiency measure does not assess the absolute quality of forecasts, rather it assess the relative merits of long-maturity futures price and a forecast based on the regression (1.4). The calculated two adjusted coefficient of determination like measures $\bar{R}_1^2$ and $\bar{R}_2^2$ from Equation (1.9) and (1.10) gives interesting results. The negative measure of $\bar{R}_2^2$ in all metal and WTI futures market among most of the maturities in Table 1.6 indicate that long-maturity futures price is not a successful predictor of short maturity futures price. Moreover, especially the $\bar{R}_2^2$ measures from live cattle and GBP/USD exchange rate are quite impressive as $\bar{R}_2^2$ measures the value of the variability explained in short-maturity futures price through the prediction from long-maturity futures price alone. It is therefore possible to conclude that the long-maturity futures price is relatively a successful predictor of short-maturity futures price for live cattle and exchange rate markets. This is in fact in line with findings from ECM given in Table 1.5e and Table 1.5f as we found that coefficient of b_0 (long maturity futures price changes) is highly significant and closest to unity in these two markets almost among all maturities.

Last but not least, we found very interesting results from 60 days forecast horizon. We found that efficiency drops to around 50% for all markets apart from live cattle and exchange rate as shown in Table 1.7. A large negative value of $\bar{R}_2^2$ implies that long-maturity futures price is substantially inferior to predict short-maturity futures price from 60 days forecast horizon in all metal futures and WTI crude oil futures market. Moreover, the high value of 'deviation of p from unity' in metal and crude oil market also confirms that long-maturity futures price are not useful to predict short-maturity futures price in those markets from 60 days forecast horizon. These results indicate some useful information for market participants. For example, the proportionate cost of hedging is given by $\frac{(F_{t-1}-F_t)}{F_t} = F_{t-1} - F_t$ and hence it corresponds to the forecast error in our analysis. Having 50% inefficiency from 60 days forecast horizon can be interpreted as the variance of proportionate hedging cost would be 50% lower if the long maturity futures price was an efficient predictor of short maturity futures price.

Finally, the high efficiency rate in live cattle and GBP/USD market from 60 days forecast horizon is quite interesting. This result might come from the fact that these two markets have futures contracts traded every two months unlike others whose futures contracts traded every month. Hence, when a futures contract expires and rolls over to the next one there will be two months to expiration and all available information will be already incorporated from that horizon. Table 1.2 presents the trading volume of a chosen contract (December 2011) for all commodities on the last trading day, 1 month before the last trading day and 2 months before the last trading day as well as the total trading volumes during the 1 month and 2 month maturity of that contract. It indicates that the trading volume has the highest number during the last trading month in all metal and WTI Crude Oil futures markets in comparison to Live Cattle and GBP/USD exchange rate futures market where the volume is higher during the two month before expiration period than the last trading month. This in fact indicates that the efficiency measure depends on the forecast horizon and the availability of futures contracts.

1.5 Conclusion

In futures markets, contracts with different maturities are traded. Hence, as Kawamoto and Hamori (2011) points out, if a futures price is the market expectation of a spot price at some future time, then a long-maturity futures price can be seen as the market expectation of a short-maturity futures price at some future time. In this study, the futures price with differing maturities, up to 8-month maturity, for aluminium, copper, nickel, zinc, live cattle, GBP/USD exchange rate and WTI crude oil are analysed from both long-run and short-run perspective. Moreover, a quantitative measure of the degree of inefficiency is used in order to analyse how well or badly those markets are functioning.

The evidence suggests that there is co-integration relationship exists among all maturities and all commodities studied. However, the existence of co-integrating vector of [1, -1] between long-maturity and short-maturity futures prices differs among maturities although mostly cannot be rejected. This in fact in contrast to findings of Kawamoto and Hamori (2011) of WTI crude oil market as the existence of co-integrating vector is rejected in four maturities out of eight in our study although they found it among all maturities. Moreover, it is found that there is evidence of inefficiencies in all the markets studied and among most of the maturities. The findings suggest that the past price information is useful to predict short-maturity futures prices in all markets as lagged long and short maturity futures prices are found to be significant in our analysis. Moreover, the null hypothesis of short-run market efficiency is rejected in all commodities and almost among all maturities but live cattle and exchange rate. It is found that live cattle and exchange rate market performs best in terms of both long-run and short-run market efficiency.

However, 'failure to reject a null hypothesis of market efficiency does not necessarily imply strong evidence of support for that hypothesis' (Kellard et al., 1999) and the simple observation of that a market is efficient or not efficient provides limited information for market participants. Thus, in this paper the degree of inefficiency in a market is measured in terms of the ability of long-maturity futures price to forecast the corresponding short-maturity futures price relative to the forecast produced by the best fitting ECM. The results show that all markets studied is in fact above 90% efficient with a forecast horizon of 30 days. This also indicates that rejecting null hypothesis of market efficiency does not imply that a market is inefficient as the market efficiency was rejected although there is over 90% efficiency in all metal and crude oil futures market in our study.

The analysis was repeated for all markets, extending the horizon to 60 days. We found very interesting results. The degree of efficiency drops to around 50% in all markets apart from live cattle and exchange rate. In particular, this result comes from the fact that prediction through only long-maturity futures price is inferior with 60 days forecast horizon having negative R_2^2 and large measure of deviation of p (long-run equilibrium coefficient) from unity. In other words, a one-month maturity futures price can predict 0-month maturity price better than a 2-month maturity price in all markets but live cattle and exchange rate. We argue that this result might come from the fact that apart from live cattle and GBP/USD exchange rate all other futures have contracts traded every month. This indicates that there is a contract expiring every month in all other markets while it is every two months in live cattle and exchange rate and hence all the available information is incorporated in a monthly basis in those markets. Moreover, the volume of trading in these markets also confirms this hypothesis. We found that apart from live cattle and exchange rate markets, the trading volume is highest on the last trading month, whereas it has the highest volume two and three months before the expiration of the contract for these two markets. Overall, these results indicate that the forecast horizon should be chosen according to number of contracts traded per year.

Table 1.1 Number of Observations

This table shows the number of observations in each commodity class. The numbers of observations are same across different maturities, for example all maturity of Aluminium futures contracts has 213 observations each indicating that there are total 1917 observations as there are 9 different maturity time series.

	Aluminium	Copper	Nickel	Zinc	WTI Crude Oil	Live Cattle	GBP/USD FX Rate
No. of Obs for each maturity	213	213	213	213	264	192	140
Total Obs	1917	1917	1917	1917	2376	1728	1260

Table 1.2 Volume of Trades

This table represents the Trading Volumes of a chosen contract across all commodities studied on the last trading day, one month before the last trading day and two months before the last trading day. Total volumes give the total number of trading during the last trading month before expiration and two month before expiration. The chosen contract is the same for all commodities and it is December 2011 contract.

	Aluminium	Copper	Nickel	Zinc	WTI Crude	Live Cattle	GBP/USD FX Rate
Last trading day	206,223	36,054	10,309	38,708	38,551	1,652	2,071
1 month before	35,136	21,045	4,308	13,265	389,241	8,467	78,187
2 month before	42,964	13,256	2,600	22,454	69,126	24,518	121,880
Total Volume 1-mo maturity	1,015,241	345,527	87,914	323,550	6,754,716	99,695	1,796,994
Total Volume 2-mo maturity	726,233	343,994	66,877	295,464	3,689,110	441,302	2,291,271

Table 1.3 Test of Cointegration Rank

This table presents the cointegration rank test between different maturity futures of four metals, one agricultural, one financial and one energy futures markets. The results are gained using Johansen cointegration methodology in Equation (1.3). P-values are for the null hypothesis of no cointegration to the alternative one cointegration and one cointegration to the alternative more than one cointegration.

		Aluminium			Copper			Nickel			Zinc		
	$H_0: r$	Trace	Max-Eigen	p-value	Trace	Max-Eigen	p-value	Trace	Max-Eigen	p-value	Trace	Max-Eigen	p-value
0-1 mo. Maturity	0	143.0	137.9	0.0	164.9	163.5	0.0	159.7	157.0	0.0	159.2	156.7	0.0
	1	5.1	5.1	0.3	1.4	1.4	0.9	2.7	2.7	0.6	2.5	2.5	0.7
1-2 mo. Maturity	0	120.9	115.5	0.0	121.8	119.9	0.0	163.9	160.8	0.0	132.0	129.2	0.0
	1	5.4	5.4	0.2	1.9	1.9	0.8	3.1	3.1	0.6	2.9	2.9	0.6
2-3 mo. Maturity	0	152.5	147.3	0.0	170.0	168.3	0.0	148.1	145.2	0.0	175.0	172.0	0.0
	1	5.1	5.1	0.3	1.8	1.8	0.8	2.9	2.9	0.6	3.0	3.0	0.6
3-4 mo. Maturity	0	169.6	164.8	0.0	163.7	162.1	0.0	174.8	172.1	0.0	156.2	153.2	0.0
	1	4.7	4.7	0.3	1.7	1.7	0.9	2.6	2.6	0.7	3.0	3.0	0.6
4-5 mo. Maturity	0	154.1	148.0	0.0	152.0	150.3	0.0	141.4	138.6	0.0	145.4	142.9	0.0
	1	6.1	6.1	0.2	1.7	1.7	0.8	2.8	2.8	0.6	2.6	2.6	0.7
5-6 mo. Maturity	0	142.4	137.3	0.0	148.9	147.2	0.0	151.7	149.2	0.0	159.7	157.7	0.0
	1	5.1	5.1	0.3	1.6	1.6	0.9	2.5	2.5	0.7	2.0	2.0	0.8
6-7 mo. Maturity	0	147.5	141.5	0.0	137.6	135.7	0.0	156.5	153.3	0.0	144.6	141.9	0.0
	1	6.0	6.0	0.2	1.9	1.9	0.8	3.2	3.2	0.6	2.7	2.7	0.7
7-8 mo. Maturity	0	152.7	147.5	0.0	131.0	129.2	0.0	149.9	146.9	0.0	150.1	147.8	0.0
	1	5.2	5.2	0.3	1.8	1.8	0.8	3.0	3.0	0.6	2.3	2.3	0.7

Table 1.3 continues

		Live Cattle			GBP/USD			WTI Crude Oil		
	$H_0: r$	Trace	Max-Eigen	p-value	Trace	Max-Eigen	p-value	Trace	Max-Eigen	p-value
0-1 mo. Maturity	0	97.6	96.2	0.0	39.3	33.0	0.0	89.4	88.4	0.0
	1	1.3	1.3	0.3	6.3	6.3	0.2	1.0	1.0	0.3
1-2 mo. Maturity	0	30.9	30.8	0.0	57.6	51.7	0.0	62.7	61.6	0.0
	1	0.1	0.1	0.8	5.9	5.9	0.2	1.1	1.1	0.3
2-3 mo. Maturity	0	89.7	88.8	0.0	52.5	45.7	0.0	27.5	27.0	0.0
	1	1.0	1.0	0.3	6.8	6.8	0.1	0.5	0.5	0.5
3-4 mo. Maturity	0	63.2	62.1	0.0	36.6	30.2	0.0	37.3	36.9	0.0
	1	1.1	1.1	0.3	6.3	6.3	0.2	0.4	0.4	0.5
4-5 mo. Maturity	0	108.8	107.8	0.0	53.5	47.5	0.0	63.0	62.3	0.0
	1	1.1	1.1	0.3	6.0	6.0	0.2	0.7	0.7	0.4
5-6 mo. Maturity	0	82.2	81.3	0.0	57.0	50.5	0.0	70.3	69.9	0.0
	1	0.8	0.8	0.4	6.4	6.4	0.2	0.4	0.4	0.6
6-7 mo. Maturity	0	119.9	119.0	0.0	41.1	34.5	0.0	145.5	144.8	0.0
	1	0.8	0.8	0.4	6.6	6.6	0.2	0.6	0.6	0.4
7-8 mo. Maturity	0	76.9	75.5	0.0	49.1	43.2	0.0	80.6	80.1	0.0
	1	1.4	1.4	0.2	5.9	5.9	0.2	0.5	0.5	0.5

Table 1.4 Test of Cointegrating Vectors [1, -1]

This table shows the analysis of the existence of a cointegrating vector [1, -1] between different maturity price series. Analysis is done by putting restriction in Johansen cointegration methodology in Equation (1.3). P-values are for the null hypothesis that the cointegrating vector of [1, -1] exist.

	0-1 mo. maturity	1-2 mo. maturity	2-3 mo. maturity	3-4 mo. maturity	4-5 mo. maturity	5-6 mo. maturity	6-7 mo. maturity	7-8 mo. maturity
				Aluminium Futures				
X^2	0.02	0.01	0.09	2.13	0.72	1.84	3.35	1.91
p-value	0.90	0.94	0.76	0.14	0.40	0.17	0.07	0.17
				Copper Futures				
X^2	4.07	0.30	0.05	1.13	0.01	0.48	2.85	0.01
p-value	0.04	0.58	0.83	0.29	0.93	0.49	0.09	0.94
				Nickel Futures				
X^2	2.00	2.78	2.86	0.29	0.35	5.03	4.16	0.23
p-value	0.16	0.10	0.09	0.59	0.55	0.02	0.04	0.63
				Zinc Futures				
X^2	2.84	0.01	1.02	4.30	0.96	2.39	3.68	0.57
p-value	0.09	0.93	0.31	0.04	0.33	0.12	0.06	0.45
				Live Cattle Futures				
X^2	0.01	0.95	1.19	3.29	0.56	1.60	4.80	3.45
p-value	0.92	0.33	0.28	0.07	0.46	0.21	0.03	0.06
				GBP/USD Futures				
X^2	0.04	0.04	0.11	0.16	0.05	0.20	0.47	0.05
p-value	0.84	0.84	0.74	0.69	0.83	0.66	0.49	0.83
				WTI Crude Oil Futures				
X^2	2.16	3.15	6.45	1.80	5.91	6.53	1.39	1.82
p-value	0.14	0.08	0.01	0.18	0.02	0.01	0.24	0.18

Table 1.5a Aluminium Futures ECM Results

This table represent the result from short-run market efficiency, Equation (1.4);

$$\Delta F_{t+1}^{(s-1)} = c - p\, u_t + b_0\, \Delta F_t^s + \sum_{i=1}^{m} a_i \Delta\, F_{t+1-i}^{(s-1)} + \sum_{j=1}^{n} b_j\, \Delta F_{t-j}^{(s)} + \varepsilon_{t+1}$$

This equation implies that past price information is useful to predict changes in short-maturity price which violates market efficiency. The conditions; $p > 0$ because short-maturity futures price changes respond to the deviations from the long-run equilibrium, $b_0 \neq 0$ because all available new information, concerning short-maturity futures price changes, to be reflected immediately into long-maturity futures price and $a_i = b_i = 0$ as the past price information has been already incorporated into the long-maturity futures price should be established and the Wald test for the null hypothesis $p = 1$, $p\beta = b_0$, $a_i = b_j = 0$ is given in the last row. The underlined numbers are heteroscedasticity consistent standard errors, the numbers in bold are t-statistics.

Dependent Variable	0-mo. maturity	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity
Independent Variable	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity	8-mo. maturity
	-0.003	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001	0.000
c	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	-0.612	**-0.251**	**-0.333**	**-0.402**	**-0.249**	**-0.171**	**-0.175**	**-0.029**
	1.547	1.020	0.912	0.973	0.684	0.958	0.769	0.794
P	0.323	0.365	0.333	0.313	0.381	0.392	0.376	0.363
	4.794	**2.793**	**2.739**	**3.104**	**1.795**	**2.441**	**2.047**	**2.188**
	0.676	0.599	0.568	0.353	0.760	0.788	0.559	0.678
b_0	0.186	0.181	0.186	0.208	0.212	0.217	0.197	0.199
	3.645	**3.307**	**3.059**	**1.699**	**3.590**	**3.633**	**2.840**	**3.414**
	0.877	0.450	0.388	0.632	-0.041	0.259	0.307	0.228
a_1	0.286	0.330	0.310	0.268	0.357	0.374	0.348	0.327
	3.069	**1.365**	**1.251**	**2.360**	**-0.114**	**0.694**	**0.884**	**0.698**
	0.767	0.427	0.480	0.463	0.017	0.447	0.164	0.059
a_2	0.238	0.297	0.287	0.204	0.323	0.346	0.316	0.270
	3.219	**1.439**	**1.675**	**2.268**	**0.051**	**1.291**	**0.521**	**0.219**
	0.451	0.317	0.582		0.309	0.141	-0.007	-0.047
a_3	0.181	0.261	0.257		0.269	0.309	0.291	0.202
	2.494	**1.214**	**2.265**		**1.151**	**0.455**	**-0.024**	**-0.231**
		0.466	0.450		0.347	0.379	-0.198	
a_4	-	0.228	0.192	-	0.202	0.259	0.248	-
		2.047	**2.346**		**1.717**	**1.465**	**-0.796**	
		0.285				-0.108	0.029	
a_5	-	0.182	-	-	-	0.192	0.186	-
		1.564				**-0.561**	**0.155**	
	-0.650	-0.252	-0.348	-0.278	0.148	-0.336	0.013	0.039
b_1	0.239	0.293	0.280	0.198	0.313	0.347	0.324	0.270
	-2.718	**-0.857**	**-1.240**	**-1.408**	**0.474**	**-0.969**	**0.041**	**0.143**
	-0.322	-0.171	-0.468	0.084	-0.206	-0.072	0.101	0.114
b_2	0.181	0.258	0.251	0.071	0.265	0.311	0.298	0.201
	-1.772	**-0.662**	**-1.862**	**1.183**	**-0.780**	**-0.233**	**0.338**	**0.567**
	0.108	-0.327	-0.334		-0.200	-0.288	0.359	0.142
b_3	0.072	0.225	0.187		0.201	0.258	0.250	0.070
	1.507	**-1.456**	**-1.785**		**-0.993**	**-1.116**	**1.438**	**2.029**
		-0.345	-0.048		-0.064	0.108	-0.042	
b_4	-	0.180	0.069	-	0.071	0.197	0.186	-
		-1.916	**-0.694**		**-0.906**	**0.550**	**-0.224**	
		-0.136				-0.124	-0.159	
b_5	-	0.071	-	-	-	0.072	0.074	-
		-1.924				**-1.736**	**-2.158**	
Wald test	0.005	0.004	0.012	0.001	0.012	0.050	0.001	0.018

Table 1.5b Copper Futures ECM Results

This table created the same way as Table 1.3a using Copper futures series. The underlined numbers are heteroscedasticity consistent standard errors, the numbers in bold are t-statistics.

Dependent Variable	0-mo. maturity	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity
Independent Variable	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity	8-mo. maturity
	-0.001	-0.001	0.000	-0.003	0.003	0.000	-0.003	0.003
c	0.006	0.006	0.006	0.006	0.005	0.006	0.005	0.005
	-0.091	**-0.101**	**-0.024**	**-0.477**	**0.464**	**0.075**	**-0.617**	**0.679**
	0.749	0.786	0.645	0.998	0.463	0.595	1.089	0.256
ρ	0.277	0.342	0.235	0.368	0.190	0.252	0.328	0.131
	2.706	**2.297**	**2.750**	**2.712**	**2.433**	**2.360**	**3.319**	**1.955**
	0.636	0.632	0.769	0.882	0.646	0.660	1.154	0.485
b_0	0.193	0.158	0.157	0.203	0.186	0.192	0.197	0.190
	3.304	**3.995**	**4.883**	**4.335**	**3.471**	**3.445**	**5.871**	**2.555**
	0.295	0.290	0.053	0.290		0.159	0.164	0.005
a_1	0.195	0.318	0.162	0.293		0.185	0.272	0.204
	1.512	**0.911**	**0.327**	**0.992**	-	**0.859**	**0.603**	**0.025**
		0.330		0.293			0.337	
a_2		0.290		0.199			0.190	-
	-	**1.138**	-	**1.471**	-	-	**1.775**	-
		0.326						
a_3		0.257						
	-	**1.271**	-	-	-	-	-	-
		0.408						
a_4		0.215						
	-	**1.900**	-	-	-	-	-	-
		0.424						
a_5		0.163						
	-	**2.601**	-	-	-	-	-	-
	0.069	-0.139	0.133	-0.123		0.134	-0.252	0.110
b_1	0.069	0.287	0.070	0.201		0.072	0.203	0.068
	0.997	**-0.483**	**1.899**	**-0.612**	-	**1.853**	**-1.243**	**1.622**
		-0.310		0.002			0.101	
b_2		0.257		0.072			0.072	-
	-	**-1.204**	-	**0.026**	-	-	**1.390**	-
		-0.443						
b_3		0.215						
	-	**-2.060**	-	-	-	-	-	-
		-0.395						
b_4		0.164						
	-	**-2.414**	-	-	-	-	-	-
		-0.098						
b_5		0.071						
	-	**-1.377**	-	-	-	-	-	-
Wald test	0.003	0.005	0.002	0.039	0.002	0.000	0.002	0.000

Table 1.5c Nickel Futures ECM Results

This table created the same way as Table 1.3a using Nickel futures series. The underlined numbers are heteroscedasticity consistent standard errors, the numbers in bold are t-statistics.

Dependent Variable	0-mo. maturity	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity
Independent Variable	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity	8-mo. maturity
	0.001	-0.005	0.002	0.000	0.000	-0.001	0.002	-0.003
c	0.007	0.008	0.007	0.007	0.007	0.007	0.007	0.007
	0.150	**-0.706**	**0.318**	**-0.001**	**0.023**	**-0.071**	**0.315**	**-0.480**
	0.524	1.817	0.481	0.732	0.622	0.743	0.580	1.053
ρ	0.254	0.479	0.296	0.297	0.290	0.375	0.196	0.362
	2.062	**3.792**	**1.623**	**2.463**	**2.142**	**1.981**	**2.955**	**2.909**
	0.514	0.896	0.363	0.639	0.867	0.384	0.671	0.973
b_0	0.171	0.210	0.187	0.206	0.222	0.190	0.193	0.178
	3.001	**4.257**	**1.943**	**3.095**	**3.910**	**2.020**	**3.478**	**5.467**
	0.035	0.965	0.214	0.127	-0.198	0.451		0.188
a_1	0.184	0.433	0.258	0.208	0.213	0.343		0.306
	0.193	**2.230**	**0.829**	**0.609**	**-0.928**	**1.315**	-	**0.613**
		0.864	0.281			0.359		0.012
a_2		0.383	0.192			0.312		0.244
	-	**2.258**	**1.466**	-	-	**1.151**	-	**0.048**
		0.728				0.154		-0.096
a_3		0.330				0.264		0.174
	-	**2.204**	-	-	-	**0.582**	-	**-0.553**
		0.597				0.198		
a_4		0.278				0.194		-
	-	**2.151**	-	-	-	**1.018**	-	-
		0.390						
a_5		0.195						-
	-	**2.005**	-	-	-	-	-	-
	0.172	-0.721	-0.169	0.156	0.201	-0.223		0.117
b_1	0.066	0.386	0.185	0.069	0.071	0.314		0.251
	2.610	**-1.868**	**-0.917**	**2.267**	**2.838**	**-0.710**	-	**0.465**
		-0.729	-0.052			-0.230		0.058
b_2		0.332	0.069			0.262		0.180
	-	**-2.196**	**-0.747**	-	-	**-0.879**	-	**0.320**
		-0.488				-0.069		0.172
b_3		0.282				0.189		0.072
	-	**-1.734**	-	-	-	**-0.363**	-	**2.374**
		-0.373				-0.016		
b_4		0.198				0.071		-
	-	**-1.881**	-	-	-	**-0.223**	-	-
		0.078						
b_5		0.076						-
	-	**1.027**	-	-	-	-	-	-
Wald test	0.004	0.160	0.003	0.032	0.031	0.010	0.066	0.067

Table 1.5d Zinc Futures ECM Results

This table created the same way as Table 1.3a using Zinc futures series. The underlined numbers are heteroscedasticity consistent standard errors, the numbers in bold are t-statistics.

Dependent Variable	0-mo. maturity	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity
Independent Variable	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity	8-mo. maturity
	-0.003	-0.001	0.001	-0.003	0.001	-0.002	-0.001	-0.002
c	0.005	0.006	0.005	0.005	0.005	0.005	0.005	0.005
	-0.530	**-0.245**	**0.180**	**-0.526**	**0.216**	**-0.366**	**-0.212**	**-0.389**
	1.810	1.065	0.579	1.678	0.612	1.285	0.881	0.987
ρ	0.376	0.374	0.226	0.399	0.169	0.340	0.325	0.406
	4.820	**2.846**	**2.565**	**4.211**	**3.628**	**3.786**	**2.714**	**2.432**
	0.755	0.740	0.666	0.878	0.684	0.294	0.830	0.687
b_0	0.174	0.173	0.146	0.177	0.166	0.159	0.188	0.194
	4.340	**4.271**	**4.567**	**4.967**	**4.128**	**1.844**	**4.417**	**3.534**
	1.063	0.372	0.004	0.834		1.032	0.116	0.386
a_1	0.330	0.342	0.157	0.328		0.308	0.291	0.361
	3.217	**1.088**	**0.024**	**2.544**	-	**3.351**	**0.400**	**1.068**
	0.934	0.343		0.673		0.826	0.053	0.508
a_2	0.266	0.308		0.256		0.275	0.245	0.320
	3.510	**1.111**	-	**2.631**	-	**3.010**	**0.218**	**1.587**
	0.655	0.214		0.198		0.563	0.101	0.282
a_3	0.187	0.266		0.178		0.226	0.175	0.263
	3.512	**0.803**	-	**1.109**	-	**2.489**	**0.578**	**1.071**
		0.530				0.390		0.520
a_4		0.228				0.164		0.194
		2.326	-	-	-	**2.380**	-	**2.681**
		0.394						
a_5		0.170						-
		2.320	-	-	-	-	-	-
	-0.829	-0.201	0.124	-0.483		-0.780	0.092	-0.440
b_1	0.271	0.307	0.069	0.259		0.279	0.253	0.317
	-3.063	**-0.655**	**1.809**	**-1.863**	-	**-2.795**	**0.362**	**-1.387**
	-0.687	-0.163		-0.228		-0.543	-0.020	-0.164
b_2	0.193	0.269		0.181		0.224	0.183	0.254
	-3.565	**-0.605**	-	**-1.263**	-	**-2.424**	**-0.107**	**-0.645**
	0.069	-0.358		0.180		-0.212	0.134	-0.339
b_3	0.068	0.232		0.071		0.153	0.076	0.189
	1.011	**-1.539**	-	**2.536**	-	**-1.385**	**1.762**	**-1.796**
		-0.367				0.033		-0.007
b_4		0.174				0.070		0.073
	-	**-2.110**	-	-	-	**0.463**	-	**-0.091**
		-0.038						
b_5		0.076						-
	-	**-0.497**	-	-	-	-	-	-
Wald test	0.003	0.029	0.014	0.002	0.062	0.000	0.073	0.001

Table 1.5e Live Cattle Futures ECM Results

This table created the same way as Table 1.3a with Live Cattle futures series. The underlined numbers are heteroscedasticity consistent standard errors, the numbers in bold are t-statistics.

Dependent Variable	0-mo. maturity	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity
Independent Variable	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity	8-mo. maturity
	0.001	0.002	0.001	0.000	0.000	0.000	0.001	0.000
c	0.003	0.003	0.003	0.003	0.002	0.002	0.002	0.002
	0.186	**0.665**	**0.329**	**0.068**	**0.022**	**-0.178**	**0.372**	**-0.052**
	0.812	0.453	0.826	0.848	1.275	0.960	1.086	0.853
ρ	0.163	0.166	0.204	0.113	0.127	0.084	0.214	0.226
	4.995	**2.736**	**4.039**	**7.488**	**10.038**	**11.416**	**5.077**	**3.768**
	0.878	0.904	0.959	1.071	1.058	1.025	0.990	0.887
b_0	0.069	0.069	0.057	0.053	0.061	0.057	0.060	0.063
	12.692	**13.094**	**16.870**	**20.355**	**17.451**	**18.029**	**16.490**	**14.042**
	-0.085	-0.456	-0.137	-0.145	0.156		0.102	0.025
a_1	0.131	0.151	0.179	0.083	0.089		0.188	0.207
	-0.652	**-3.015**	**-0.764**	**-1.760**	**1.751**		**0.545**	**0.120**
	-0.176	-0.257	-0.181				-0.175	0.089
a_2	0.096	0.139	0.155				0.161	0.186
	-1.832	**-1.840**	**-1.170**				**-1.090**	**0.480**
		-0.203	-0.100				-0.075	0.049
a_3		0.120	0.122				0.123	0.158
		-1.698	**-0.821**				**-0.610**	**0.314**
		-0.218	-0.124				-0.130	0.220
a_4		0.093	0.087				0.088	0.128
	-	**-2.355**	**-1.426**	-			**-1.472**	**1.720**
								0.225
a_5								0.098
	-		-	-	-			**2.289**
	-0.018	0.290	-0.010	0.064	-0.191		-0.081	0.054
b_1	0.114	0.143	0.161	0.073	0.073		0.185	0.180
	-0.154	**2.023**	**-0.060**	**0.884**	**-2.617**		**-0.436**	**0.300**
	0.062	0.139	0.109				0.098	-0.034
b_2	0.071	0.132	0.136				0.155	0.161
	0.870	**1.053**	**0.804**				**0.631**	**-0.208**
		0.128	0.099				0.062	-0.127
b_3		0.115	0.109				0.115	0.137
		1.111	**0.904**				**0.538**	**-0.928**
		0.135	0.139				0.201	-0.234
b_4		0.077	0.071				0.073	0.113
	-	**1.747**	**1.966**	-			**2.735**	**-2.071**
								-0.077
b_5								0.074
	-		-	-	-			**-1.042**
Wald test	0.051	0.098	0.037	0.085	0.065	0.458	0.005	0.069

Table 1.5f GBP/USD Futures ECM Results

This table created the same way as Table 1.3a using GBP/USD exchange rate futures series. The underlined numbers are heteroscedasticity consistent standard errors, the numbers in bold are t-statistics.

Dependent Variable	0-mo. maturity	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity
Independent Variable	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity	8-mo. maturity
	-0.001	0.000	0.000	-0.001	-0.001	0.000	0.000	-0.002
c	0.002	0.003	0.003	0.002	0.003	0.003	0.002	0.003
	-0.215	**-0.065**	**-0.061**	**-0.211**	**-0.249**	**0.181**	**-0.115**	**-0.744**
	0.658	1.123	0.926	0.646	1.022	0.939	0.660	1.050
ρ	0.190	0.269	0.116	0.186	0.252	0.110	0.195	0.251
	3.469	**4.179**	**7.996**	**3.484**	**4.058**	**8.531**	**3.386**	**4.181**
	1.003	1.134	0.972	1.008	1.092	0.989	1.036	1.073
b_0	0.050	0.061	0.068	0.051	0.060	0.066	0.052	0.060
	19.999	**18.461**	**14.262**	**19.818**	**18.212**	**15.041**	**19.778**	**17.830**
	-0.377	0.131		-0.372	0.082		-0.401	0.098
a_1	0.177	0.240		0.173	0.226		0.180	0.224
	-2.134	**0.547**		**-2.155**	**0.361**		**-2.233**	**0.437**
	-0.399	0.139		-0.330	0.089		-0.384	0.051
a_2	0.146	0.210		0.146	0.199		0.151	0.196
	-2.736	**0.663**		**-2.268**	**0.446**		**-2.550**	**0.260**
	-0.238	0.039		-0.155	0.013		-0.206	-0.003
a_3	0.107	0.178		0.108	0.171		0.109	0.169
	-2.214	**0.221**		**-1.444**	**0.077**		**-1.886**	**-0.016**
		-0.122			-0.135			-0.201
a_4		0.144			0.141			0.142
	-	**-0.843**		-	**-0.956**			**-1.416**
		-0.162			-0.152			-0.145
a_5		0.102			0.103			0.106
	-	**-1.587**	-	-	**-1.473**			**-1.368**
	0.424	-0.117		0.402	-0.092		0.434	-0.083
b_1	0.167	0.233		0.165	0.218		0.170	0.215
	2.532	**-0.504**		**2.443**	**-0.420**		**2.558**	**-0.386**
	0.320	-0.098		0.250	-0.075		0.307	-0.033
b_2	0.137	0.199		0.137	0.188		0.139	0.185
	2.333	**-0.493**		**1.820**	**-0.399**		**2.217**	**-0.179**
	0.225	-0.003		0.160	0.036		0.195	0.079
b_3	0.087	0.167		0.087	0.162		0.086	0.161
	2.596	**-0.017**		**1.833**	**0.221**		**2.284**	**0.493**
		0.140			0.146			0.176
b_4		0.132			0.129			0.132
	-	**1.060**		-	**1.130**			**1.330**
		0.208			0.185			0.172
b_5		0.087			0.089			0.091
	-	**2.401**	-	-	**2.077**			**1.896**
Wald test	0.191	0.049	0.518	0.364	0.164	0.525	0.264	0.353

Table 1.5g WTI Crude Oil Futures ECM Results

This table created the same way as Table 1.3a using WTI Crude Oil futures series. The underlined numbers are heteroscedasticity consistent standard errors, the numbers in bold are t-statistics.

Dependent Variable	0-mo. maturity	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity
Independent Variable	1-mo. maturity	2-mo. maturity	3-mo. maturity	4-mo. maturity	5-mo. maturity	6-mo. maturity	7-mo. maturity	8-mo. maturity
	0.000	0.003	0.000	-0.001	0.000	-0.002	-0.001	0.004
c	0.006	0.006	0.006	0.005	0.005	0.005	0.005	0.005
	-0.017	**0.438**	**0.008**	**-0.095**	**-0.044**	**-0.445**	**-0.197**	**0.756**
	1.013	0.402	0.757	0.903	0.578	0.839	0.898	0.152
ρ	0.224	0.269	0.293	0.324	0.366	0.311	0.362	0.087
	4.520	**1.494**	**2.581**	**2.792**	**1.582**	**2.702**	**2.483**	**1.751**
	0.513	0.496	0.579	0.879	0.872	0.506	1.038	0.729
b_0	0.203	0.250	0.284	0.284	0.316	0.270	0.284	0.285
	2.534	**1.979**	**2.035**	**3.089**	**2.762**	**1.870**	**3.658**	**2.557**
	0.527	-0.058	0.242	0.093	-0.191	0.441	-0.044	-0.456
a_1	0.202	0.248	0.230	0.275	0.294	0.253	0.275	0.280
	2.604	**-0.234**	**1.053**	**0.337**	**-0.649**	**1.743**	**-0.158**	**-1.631**
	0.347							
a_2	0.170							-
	2.041							
	-0.188	0.128	0.138	0.142	0.131	0.182	0.158	0.136
b_1	0.181	0.062	0.067	0.064	0.065	0.064	0.063	0.063
	-1.042	**2.053**	**2.068**	**2.229**	**2.032**	**2.846**	**2.492**	**2.170**
	0.002							
b_2	0.066							-
	0.026							
Wald test	0.003	0.020	0.027	0.122	0.027	0.000	0.047	0.002

Table 1.6 Degree of Efficiency Measures for 30 Days Forecast Horizon

This table presents a quantitative measure of the short-run inefficiency results using equation (1.8);

$$\varphi_c = \frac{(n-2k-2)^{-1}\sum_{t=1}^{n}\hat{\varepsilon}_t^2}{(n-1)^{-1}\sum_{t=1}^{n}[\left(f_t^{(s-1)} - f_{t-1}^{(s)}\right) - (\overline{f_t^{(s-1)} - f_{t-1}^{(s)}})]^2}$$

Here the denominator is the forecast error variance based on long-maturity futures price whereas the numerator is the estimated error variance from Equation (1.4). A ratio of 1 would implicate complete efficiency while quantities between 0 and 1 degree of inefficiency. Analysis is done from a 30 days forecast horizon.

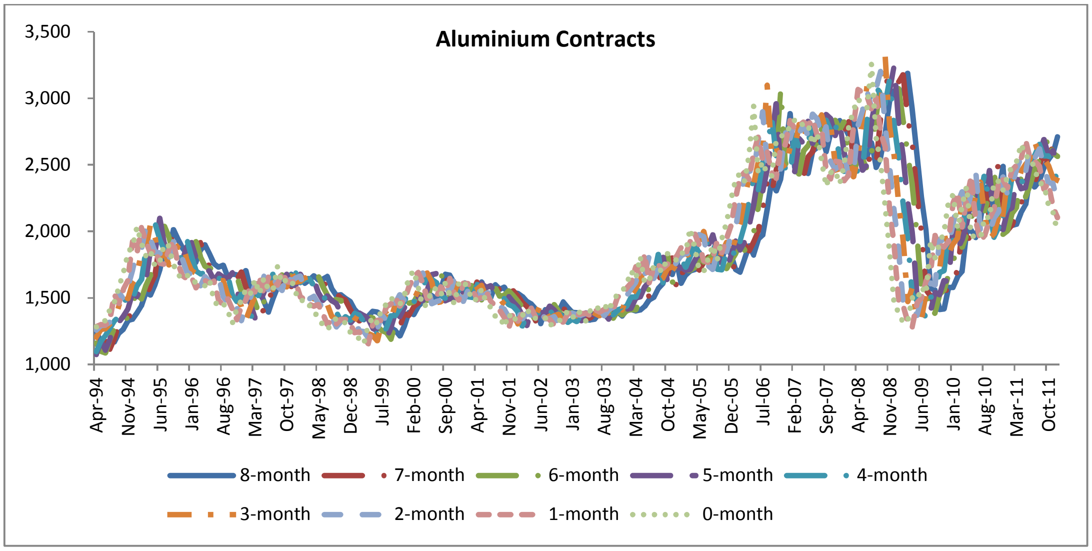
	0-1 mo. maturity	1-2 mo. maturity	2-3 mo. maturity	3-4 mo. maturity	4-5 mo. maturity	5-6 mo. Maturity	6-7 mo. maturity	7-8 mo. maturity
Aluminium Futures								
φ_c	0.93	0.92	0.94	0.91	0.93	0.96	0.89	0.95
Degree of inefficiency	0.07	0.08	0.06	0.09	0.07	0.04	0.11	0.05
Deviation of p from unity	1.70	0.05	0.26	0.09	0.83	0.11	0.61	0.57
$\bar{R}_1^2$	0.10	0.09	0.04	0.04	0.07	0.12	0.09	0.06
$\bar{R}_2^2$	0.04	0.01	-0.02	-0.05	-0.01	0.08	-0.02	0.01
Copper Futures								
φ_c	0.94	0.93	0.95	0.96	0.96	0.91	0.93	0.90
Degree of inefficiency	0.06	0.07	0.05	0.04	0.04	0.09	0.07	0.10
Deviation of p from unity	0.91	0.63	1.51	0.01	2.82	1.60	0.27	5.68
$\bar{R}_1^2$	0.07	0.09	0.11	0.09	0.07	0.07	0.16	0.09
$\bar{R}_2^2$	0.01	0.03	0.06	0.05	0.03	-0.03	0.10	-0.01
Nickel Futures								
φ_c	0.94	0.99	0.94	0.97	0.97	0.95	0.99	0.97
Degree of inefficiency	0.06	0.01	0.06	0.03	0.03	0.05	0.01	0.03
Deviation of p from unity	1.88	1.71	1.75	0.90	1.30	0.68	2.14	0.15
$\bar{R}_1^2$	0.06	0.08	0.00	0.04	0.08	0.01	0.05	0.12
$\bar{R}_2^2$	-0.01	0.07	-0.06	0.01	0.05	-0.04	0.03	0.10
Zinc Futures								
φ_c	0.95	0.98	0.96	0.94	0.99	0.89	0.98	0.93
Degree of inefficiency	0.05	0.02	0.04	0.06	0.01	0.11	0.02	0.07
Deviation of p from unity	2.16	0.17	1.87	1.70	2.30	0.84	0.37	0.03
$\bar{R}_1^2$	0.15	0.07	0.08	0.14	0.07	0.04	0.07	0.05
$\bar{R}_2^2$	0.10	0.04	0.05	0.08	0.06	-0.08	0.06	-0.02
Live Cattle Futures								
φ_c	0.93	0.93	0.89	0.93	0.98	0.99	0.88	0.92
Degree of inefficiency	0.07	0.07	0.11	0.07	0.02	0.01	0.12	0.08
Deviation of p from unity	1.15	3.30	0.85	1.34	2.16	0.48	0.40	0.65
$\bar{R}_1^2$	0.53	0.61	0.69	0.70	0.63	0.63	0.65	0.62
$\bar{R}_2^2$	0.49	0.58	0.65	0.68	0.62	0.63	0.61	0.58
GBP/USD Futures								
φ_c	0.98	0.95	0.97	1.00	0.97	0.96	0.98	0.97
Degree of inefficiency	0.02	0.05	0.03	0.00	0.03	0.04	0.02	0.03
Deviation of p from unity	1.80	0.46	0.64	1.91	0.09	0.55	1.74	0.20
$\bar{R}_1^2$	0.75	0.73	0.60	0.75	0.73	0.62	0.74	0.74
$\bar{R}_2^2$	0.75	0.72	0.59	0.75	0.72	0.60	0.74	0.73
WTI Crude Oil Futures								
φ_c	0.95	0.96	0.97	0.97	0.94	0.89	0.98	0.95
Degree of inefficiency	0.05	0.04	0.03	0.03	0.06	0.11	0.02	0.05
Deviation of p from unity	0.06	2.23	0.83	0.30	1.15	0.52	0.28	4.74
$\bar{R}_1^2$	0.08	0.02	0.03	0.05	0.04	0.08	0.06	0.04
$\bar{R}_2^2$	0.03	-0.02	0.00	0.02	-0.02	-0.03	0.04	-0.01

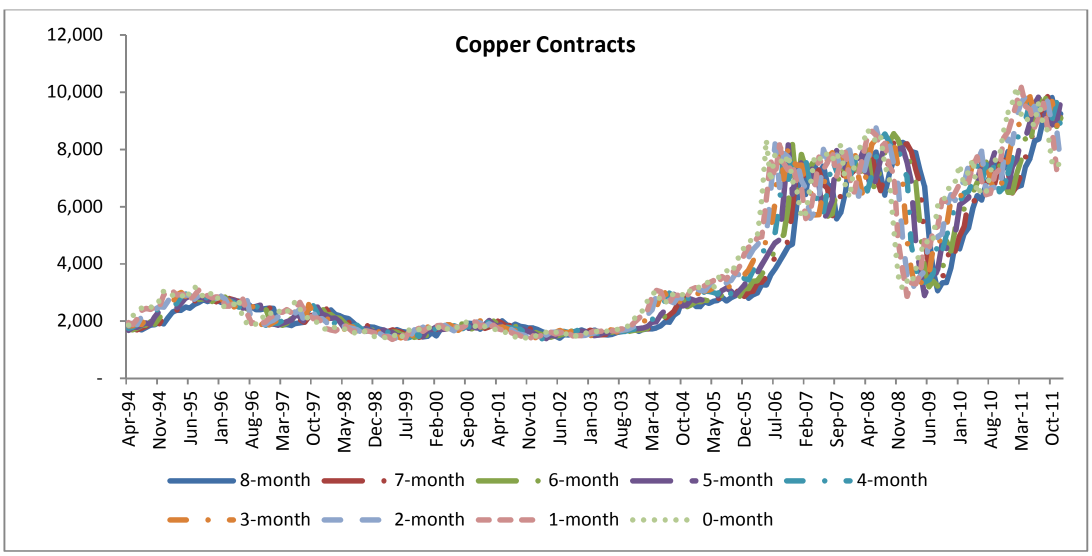
Table 1.7 Degree of Efficiency Measures for 60 Days Forecast Horizon
This table is created the same way as Table 1.4 from a 60 days forecast horizon.

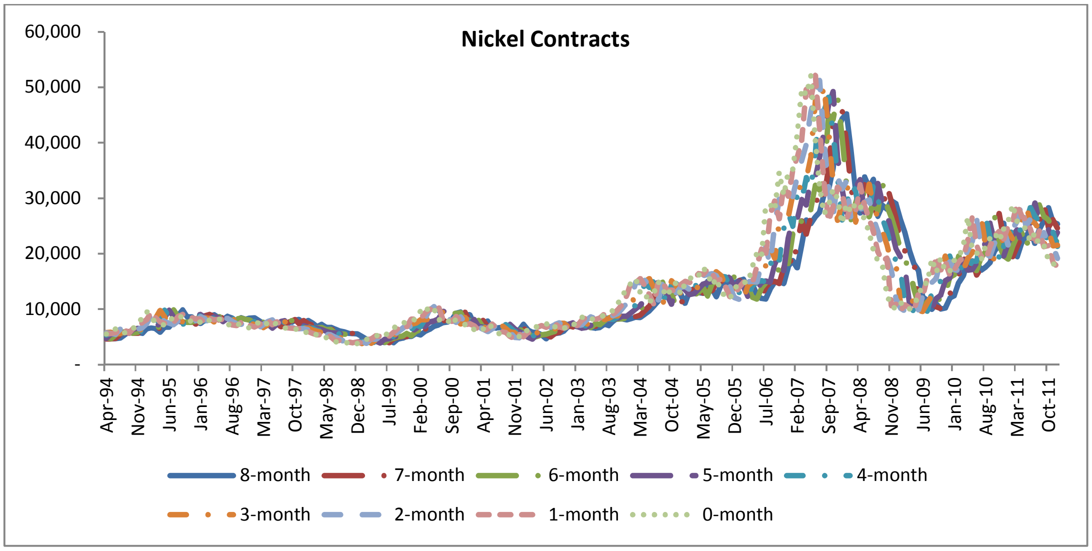
	0-2 mo. maturity	2-4 mo. maturity	4-6 mo. maturity	6-8 mo. maturity
Aluminium Futures				
φ_c	0.49	0.45	0.43	0.44
Degree of inefficiency	0.51	0.55	0.57	0.56
Deviation of p from unity	1.66	5.04	3.96	1.97
$\bar{R}_1^2$	0.05	0.01	0.09	0.05
$\bar{R}_2^2$	-0.94	-1.19	-1.11	-1.17
Copper Futures				
φ_c	0.45	0.46	0.44	0.45
Degree of inefficiency	0.55	0.54	0.56	0.55
Deviation of p from unity	1.94	2.45	4.47	3.41
$\bar{R}_1^2$	0.03	0.03	0.01	0.02
$\bar{R}_2^2$	-1.18	-1.10	-1.26	-1.18
Nickel Futures				
φ_c	0.50	0.46	0.51	0.51
Degree of inefficiency	0.50	0.54	0.49	0.49
Deviation of p from unity	2.00	2.99	2.38	2.41
$\bar{R}_1^2$	0.01	0.00	-0.02	0.01
$\bar{R}_2^2$	-0.99	-1.19	-1.00	-0.95
Zinc Futures				
φ_c	0.52	0.52	0.52	0.53
Degree of inefficiency	0.48	0.48	0.48	0.47
Deviation of p from unity	1.88	1.21	1.42	1.93
$\bar{R}_1^2$	0.01	-0.01	0.00	-0.05
$\bar{R}_2^2$	-0.90	-0.92	-0.95	-0.99
Live Cattle Futures				
φ_c	0.85	0.89	0.93	1.00
Degree of inefficiency	0.15	0.11	0.07	0.00
Deviation of p from unity	3.84	1.54	1.14	0.60
$\bar{R}_1^2$	0.20	0.39	0.37	0.24
$\bar{R}_2^2$	0.07	0.32	0.32	0.24
GBP/USD Futures				
φ_c	0.93	0.97	0.99	0.95
Degree of inefficiency	0.07	0.03	0.01	0.05
Deviation of p from unity	0.09	0.95	0.13	0.95
$\bar{R}_1^2$	0.49	0.28	0.34	0.45
$\bar{R}_2^2$	0.45	0.25	0.33	0.42
WTI Crude Oil Futures				
φ_c	0.48	0.48	0.43	0.42
Degree of inefficiency	0.52	0.52	0.57	0.58
Deviation of p from unity	3.44	3.47	3.25	4.96
$\bar{R}_1^2$	0.06	0.03	0.03	0.09
$\bar{R}_2^2$	-0.97	-1.02	-1.25	-1.14

Figure 1.1 Price series

This figure represents all price series across all maturities that are used in this research. The metal futures contracts, Aluminium, Copper, Nickel and Zinc, are all traded on the LME (London Metal Exchange) and prices are in US Dollars per tonne. Live Cattle and GBP/USD FX Rate futures contracts are traded on the CME (Chicago Mercantile Exchange); prices are US Cents per pound for former and US Dollars per British Pound for later. WTI Crude Oil futures contracts are traded on NYMEX (New York Mercantile Exchange) and prices are in US Dollars per barrel.






Nickel Contracts
60,000
50,000
40,000
30,000
20,000
10,000
-
Apr-94
Nov-94
Jun-95
Jan-96
Aug-96
Mar-97
Oct-97
May-98
Dec-98
Jul-99
Feb-00
Sep-00
Apr-01
Nov-01
Jun-02
Jan-03
Aug-03
Mar-04
Oct-04
May-05
Dec-05
Jul-06
Feb-07
Sep-07
Apr-08
Nov-08
Jun-09
Jan-10
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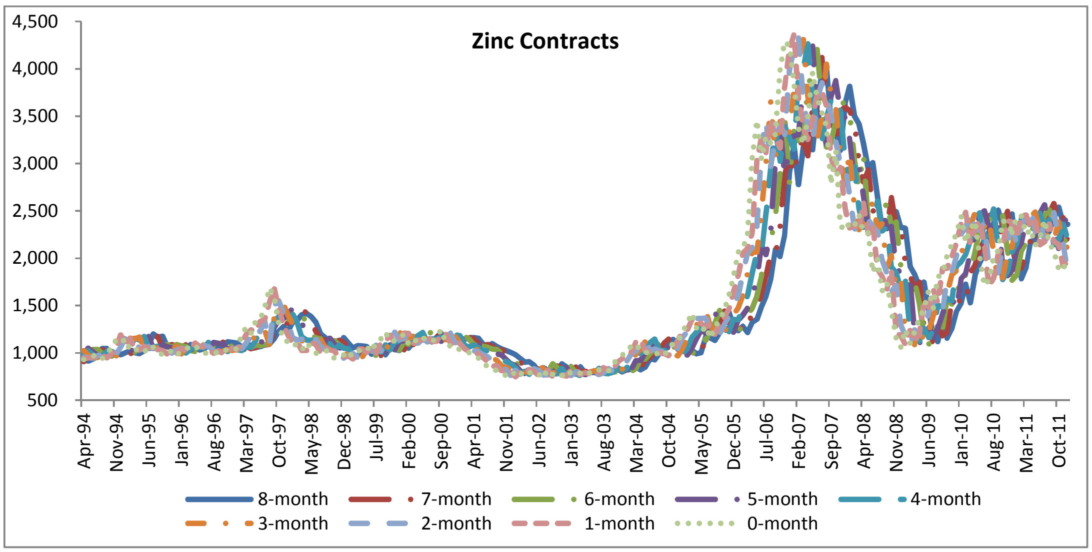
2-month
1-month
0-month


Zinc Contracts
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
Apr-94
Nov-94
Jun-95
Jan-96
Aug-96
Mar-97
Oct-97
May-98
Dec-98
Jul-99
Feb-00
Sep-00
Apr-01
Nov-01
Jun-02
Jan-03
Aug-03
Mar-04
Oct-04
May-05
Dec-05
Jul-06
Feb-07
Sep-07
Apr-08
Nov-08
Jun-09
Jan-10
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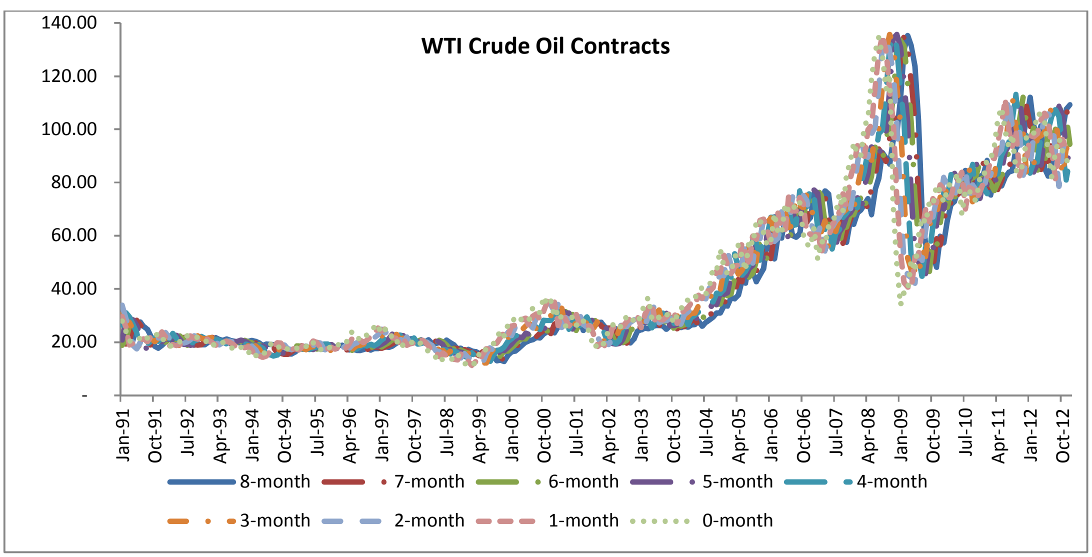
2-month
1-month
0-month


WTI Crude Oil Contracts
140.00
120.00
100.00
80.00
60.00
40.00
20.00
-
Jan-91
Oct-91
Jul-92
Apr-93
Jan-94
Oct-94
Jul-95
Apr-96
Jan-97
Oct-97
Jul-98
Apr-99
Jan-00
Oct-00
Jul-01
Apr-02
Jan-03
Oct-03
Jul-04
Apr-05
Jan-06
Oct-06
Jul-07
Apr-08
Jan-09
Oct-09
Jul-10
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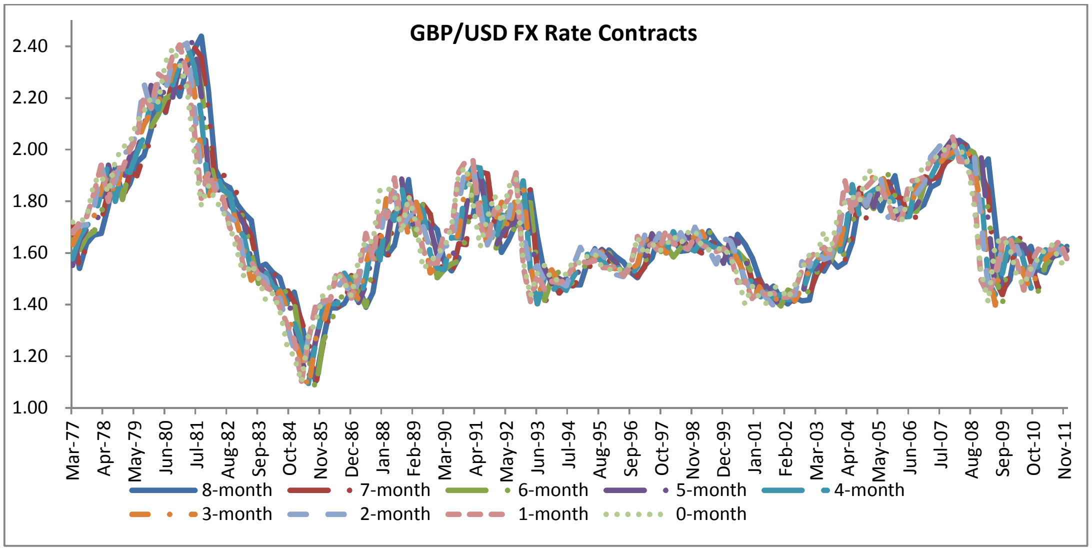
2-month
1-month
0-month


GBP/USD FX Rate Contracts
2.40
2.20
2.00
1.80
1.60
1.40
1.20
1.00
Mar-77
Apr-78
May-79
Jun-80
Jul-81
Aug-82
Sep-83
Oct-84
Nov-85
Dec-86
Jan-88
Feb-89
Mar-90
Apr-91
May-92
Jun-93
Jul-94
Aug-95
Sep-96
Oct-97
Nov-98
Dec-99
Jan-01
Feb-02
Mar-03
Apr-04
May-05
Jun-06
Jul-07
Aug-08
Sep-09
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5-month
4-month
3-month
2-month
1-month
0-month

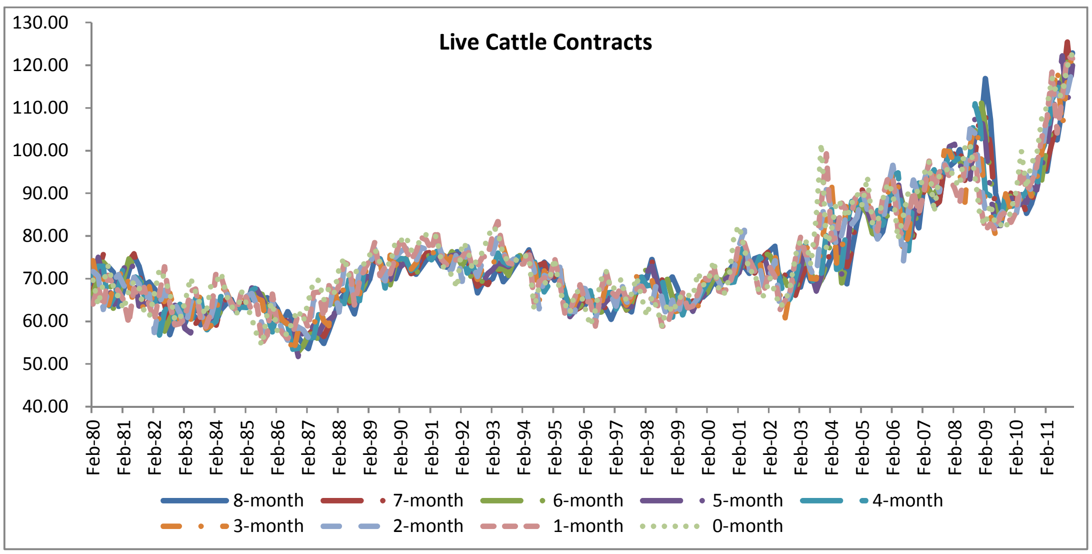

Live Cattle Contracts
130.00
120.00
110.00
100.00
90.00
80.00
70.00
60.00
50.00
40.00
Feb-80
Feb-81
Feb-82
Feb-83
Feb-84
Feb-85
Feb-86
Feb-87
Feb-88
Feb-89
Feb-90
Feb-91
Feb-92
Feb-93
Feb-94
Feb-95
Feb-96
Feb-97
Feb-98
Feb-99
Feb-00
Feb-01
Feb-02
Feb-03
Feb-04
Feb-05
Feb-06
Feb-07
Feb-08
Feb-09
Feb-10
Feb-11
8-month
7-month
6-month
5-month
4-month
3-month
2-month
1-month
0-month

Figure 1.2a Aluminium Futures Contracts

(A): ADF test with constant (series at level), (B): ADF test with constant and trend (series at level), (C): KPSS test with constant (series at level), (D): KPSS test with constant and trend (series at level), (E): ADF test with constant (series differenced once) and (F): KPSS test with constant (series differenced once)

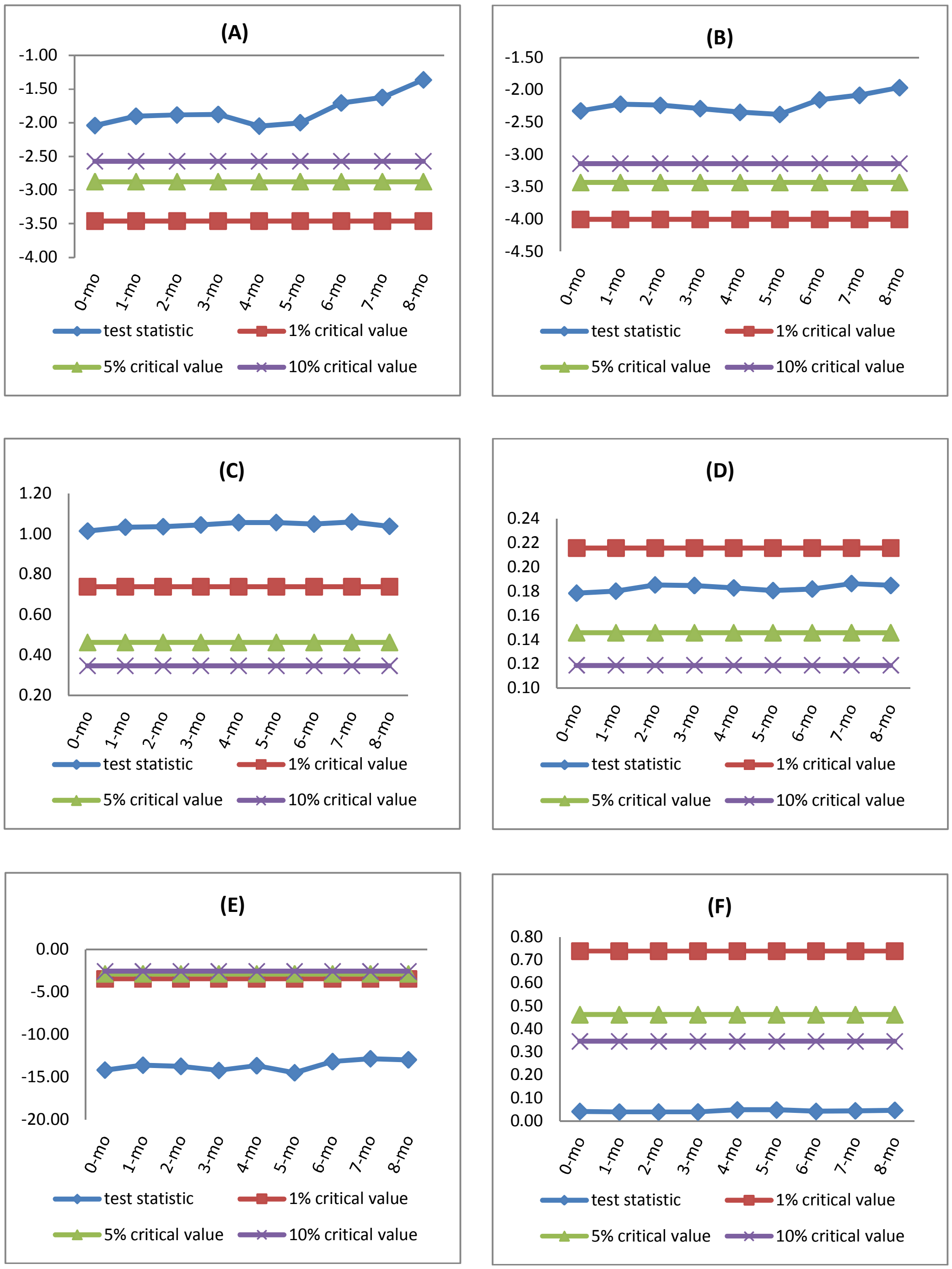


Figure 1.2b Copper Futures Contracts

(A): ADF test with constant (series at level), (B): ADF test with constant and trend (series at level), (C): KPSS test with constant (series at level), (D): KPSS test with constant and trend (series at level), (E): ADF test with constant (series differenced once) and (F): KPSS test with constant (series differenced once)

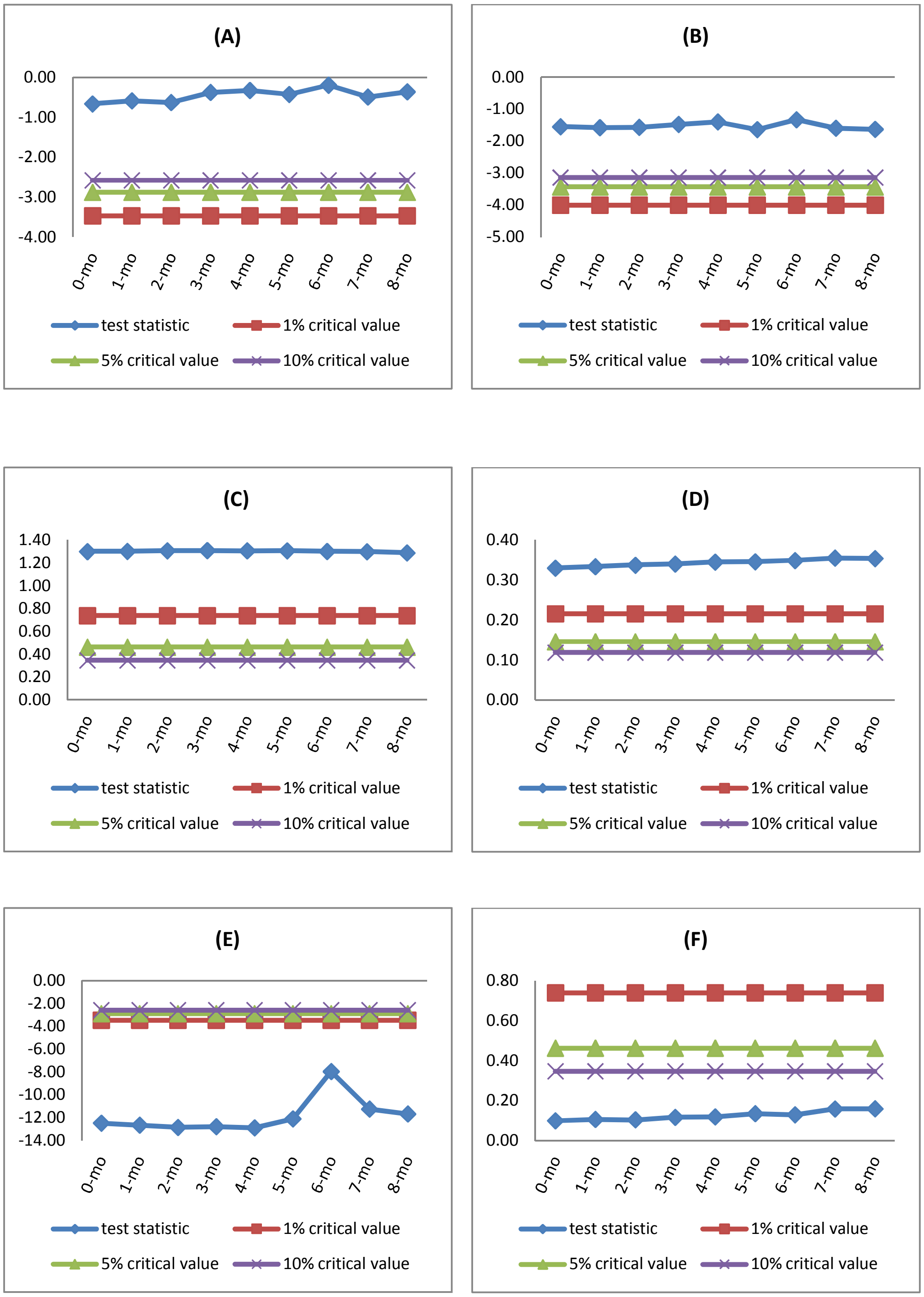


Figure 1.2c Nickel Futures Contracts

(A): ADF test with constant (series at level), (B): ADF test with constant and trend (series at level), (C): KPSS test with constant (series at level), (D): KPSS test with constant and trend (series at level), (E): ADF test with constant (series differenced once) and (F): KPSS test with constant (series differenced once)

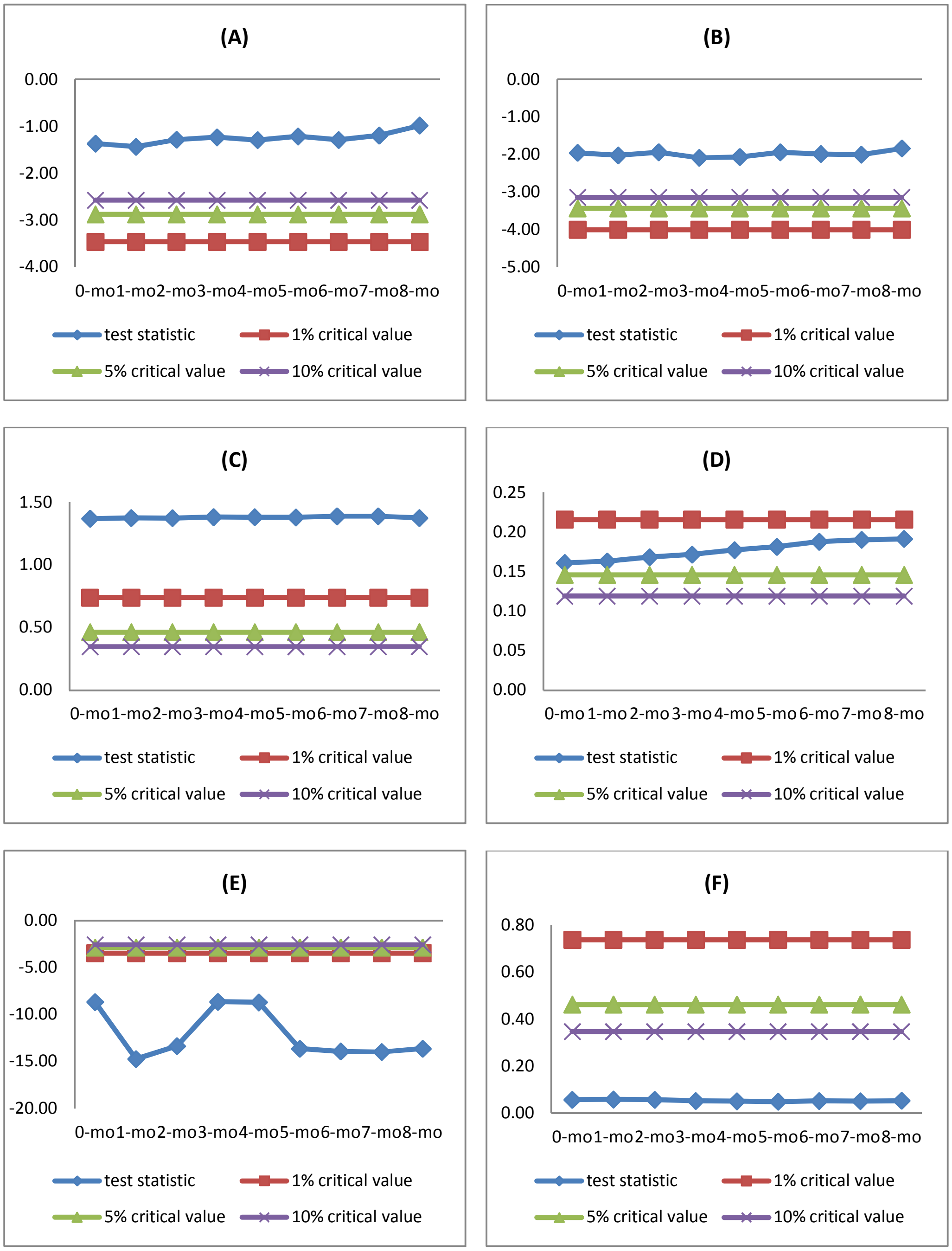


Figure 1.2d Zinc Futures Contracts

(A): ADF test with constant (series at level), (B): ADF test with constant and trend (series at level), (C): KPSS test with constant (series at level), (D): KPSS test with constant and trend (series at level), (E): ADF test with constant (series differenced once) and (F): KPSS test with constant (series differenced once)

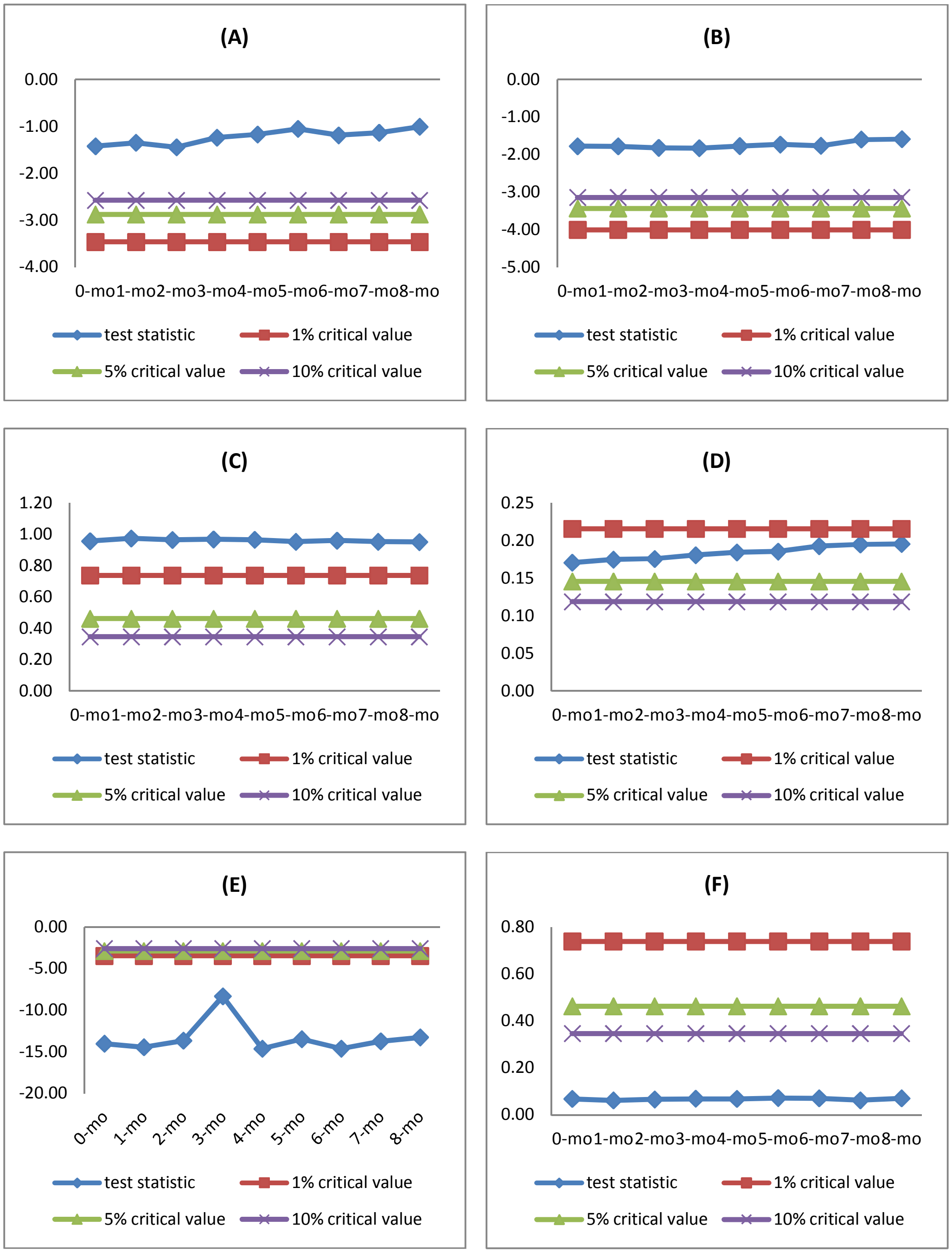


Figure 1.2e Live Cattle Futures Contracts

(A): ADF test with constant (series at level), (B): ADF test with constant and trend (series at level), (C): KPSS test with constant (series at level), (D): KPSS test with constant and trend (series at level), (E): ADF test with constant (series differenced once) and (F): KPSS test with constant (series differenced once)

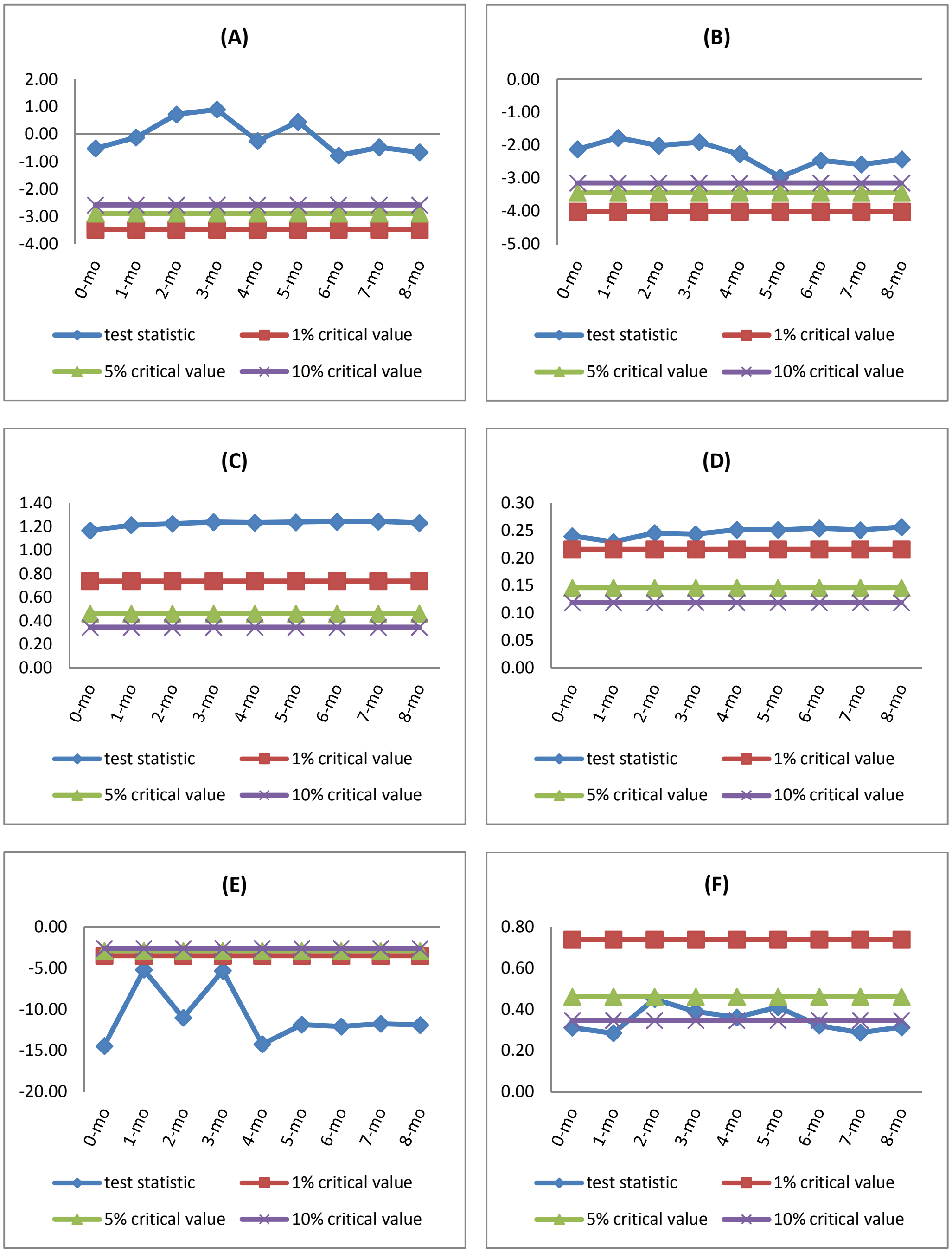


Figure 1.2f GBP/USD Exchange Rate Futures Contracts

(A): ADF test with constant (series at level), (B): ADF test with constant and trend (series at level), (C): KPSS test with constant (series at level), (D): KPSS test with constant and trend (series at level), (E): ADF test with constant (series differenced once) and (F): KPSS test with constant (series differenced once)

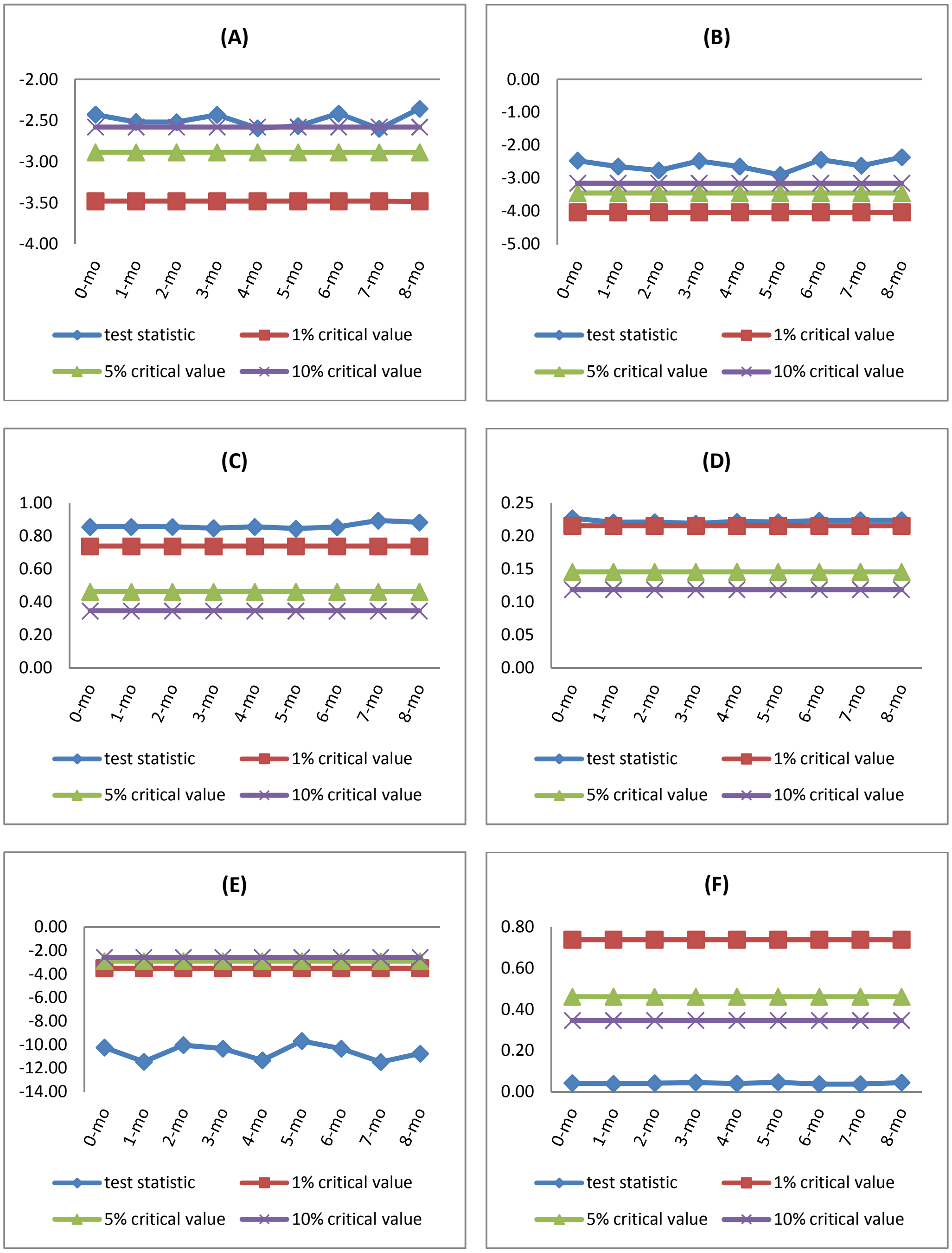
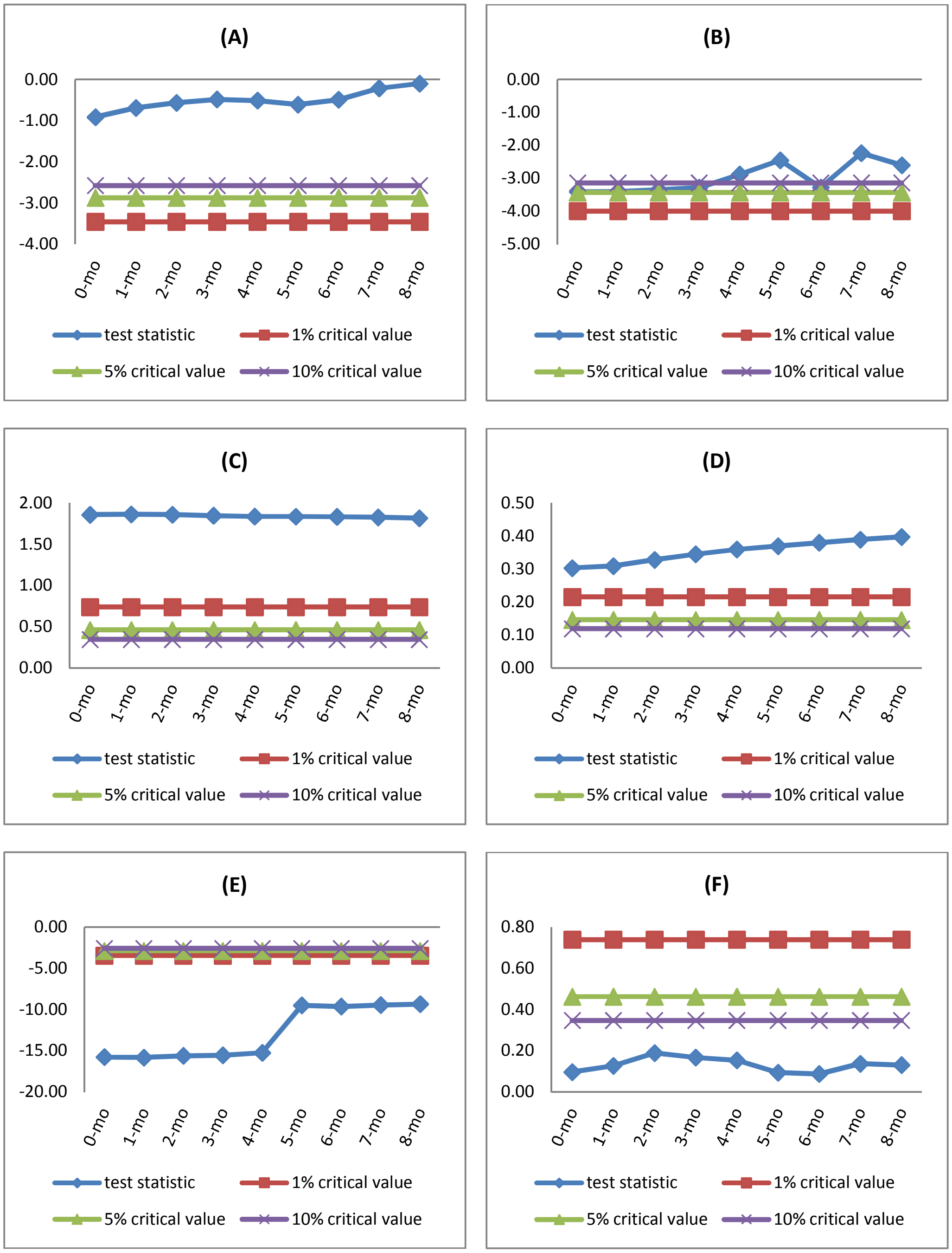


Figure 1.2g WTI Crude Oil Futures Contracts

(A): ADF test with constant (series at level), (B): ADF test with constant and trend (series at level), (C): KPSS test with constant (series at level), (D): KPSS test with constant and trend (series at level), (E): ADF test with constant (series differenced once) and (F): KPSS test with constant (series differenced once)



Chapter 2

Portfolio diversification and the commodity futures curve: examination of the time-to-maturity effect in energy, metal and agricultural markets

2.1 Introduction

Commodities have always been seen as a useful alternative asset class by investors (Gorton and Rouwenhorst, 2006; Chong and Miffre, 2010; Buyuksahin et al., 2010) due to special features such as equity-like returns, low correlations with traditional stocks and bonds, positive co-movement with inflation and a tendency to backwardation along the futures curve. Hence, these studies have analysed these benefits and indicated their usefulness for portfolio diversification. However, there have been many changes in commodity markets over the last decade. The most prominent change is that commodity prices soared in 2003 after having low and moderately fluctuating prices for almost 30 years (Delatte and Lopez, 2013). This increasing trend is often explained by the demand from emerging Asia, bio-fuel policy changes, slow supply responses, a depreciating US Dollar and low interest rates (Silvennoinen and Thorp, 2013). Moreover, the ‘financialisation’ of commodity markets since the early 2000s is often cited as a rationale for rising prices. For example, the capital flows to commodity futures markets by institutional investors has increased to $200 Billion

Dollars from $15 Billion Dollars in less than a decade (Tang and Xiong, 2012). The number of open contracts on commodity futures and options has increased fivefold between 2003 and 2012 according to Commodity Futures Trading Commission (CFTC). Hence, all these recent events in commodity markets have produced renewed questions related to the diversification benefits that had been indicated earlier.

Some of the recent studies that analysed the correlation between returns of commodities and equities indicated that the benefits of using commodities has decreased as a result of an increased correlation especially after 2008 financial crisis. Such studies include Buyuksahin and Robe (2014), Delatte and Lopez (2013), Li and Zhang (2013), Bhardwaj and Dunsby (2012), Silvennoinen and Thorp (2013), Bicchetti and Maystre (2012) and Daskalaki and Skiadopoulos (2011), just to name a few. Moreover, some of these studies examined the reasons behind this increased correlation; suggesting higher hedge-fund participation in the market, especially those that trade in both stock and commodity markets (Buyuksahin and Robe, 2014), the financial crisis (Li and Zhang, 2013), the increase in the VIX index (Silvennoinen and Thorp, 2013), and the business cycle and inflation (Bhardwaj and Dunsby, 2012). Tang and Xiong (2012) analysed the increased correlation among commodities themselves and found that the prices of non-energy commodities have become increasingly correlated with oil prices. Moreover, this trend is more significant for commodities that are traded in an index.

In this study we analyse the dependence structure between commodity and stock markets from a commodity futures curve perspective and assess the benefits for portfolio diversification. The futures curves of commodities are typically exposed to backwardation and contango shapes in the market which keeps switching every two to three years (Fuertes et al., 2010). The market is said to be in backwardation when the price of a distant maturity futures contract is lower than a short maturity one and it is in contango otherwise. When the market is in backwardation, the price of the distant maturity futures contract is expected to rise at maturity and to converge with the spot price. For example, in a backwardated market an investor with a long position in a commodity futures contract can get the benefits of the positive roll yield; while he/she is exposed to the negative roll yield when the market is in contango. Many studies in the literature used term structure signals as a trading strategy to exploit the benefits of this switching market shape. For instance, Erb and Harvey (2006) found that historical evidence shows that a trading strategy of buying 20% of commodities with highest roll returns [1]and shorting 20% of the ones with the lowest roll return in a portfolio can achieve attractive returns by holding it for a month. However, Geman and Khaorubi (2008) suggested using constant maturity futures curves in the spirit of the constant maturity notes that are popular in the interest rate market. The rationale behind it was to examine if 'there exist a 'maturity effect' in crude oil futures market when it comes to the issue of portfolio enhancement'.[2]

The main question is why should investors consider the futures curves in their portfolio? What are the benefits? Most important of all, what happened to these benefits, if there was any, after correlations increased between commodity futures and equity markets? To the best of my knowledge, Geman and Khaorubi (2008) is the only study that analyses the benefits of using different constant maturity futures contracts. They use copula functions to examine the dependence structure between the WTI crude oil futures curve and the S&P 500 index for the period between 1990 and 2006. Their results indicated that there is a negative dependency between the futures curve of oil and the S&P 500 index. This dependence parameter increases when the prices in the one market goes up (down)

[1] As the futures contracts expire, an investor has to replace the futures contract at the end of its maturity with a next-to-maturity one to be able to maintain his position in the market, where the investor rolls his/her futures position. Hence, the term structure of futures prices determines the roll return.

[2] Here, constant maturity futures contract refers to contracts that have been compiled to have a stable maturity over its time period. For example, a 12-month maturity futures contract series has 12 months till the expiration over some specified time period where the maturity is kept constant by rolling it over every month.

and the other market goes down (up), and it is flat when both markets move in a synchronous manner. Moreover, this increasing negative dependence structure is more symmetric in the 18-month futures contract indicating its usefulness in the sense that an investor does not need to worry about which market goes up or down.

This study extends the work of Geman and Khaorubi (2008) in five ways. First, our data span includes the period after the 2008 financial crisis; hence we are able to observe its impact on the benefits of using commodity futures curves. Second, we use Engle's (2002) DCC and Cappiello et al.'s (2006) ADCC model to analyse the dependence structure between returns of futures curves of commodities and equities. Third, by using these two methodologies above, we are able to estimate a conditional time-varying variance-covariance matrix that we use in our portfolio constructions and so we are able to observe also the effects of time varying dependence structure in our portfolios. Fourth, we extend our analysis to the agricultural and metal markets by, as well as oil, also using the futures curves of Soya Bean and Copper. Last but not least, we compile a traditional long-term 18-month futures contract series where an investor buys a long maturity commodity futures contract and keeps it till expiration. This allows us to compare the benefits of using a constant 18-month maturity futures contract to the traditional one.

Our analysis indicates that the correlation between futures curves of our three commodities and S&P 500 Index has increased substantially, especially after the 2008 financial crisis, although it seems that the increasing trend in correlation started well before than that. For example, the trend in WTI market appears to start in early 2002 whilst in the copper market in early 2006. Moreover, the conditional correlation *patterns* across maturities seem to be similar in all of the three commodity markets studied. In general, Soya Bean futures curves have the lowest correlation with the S&P 500 Index among all three commodities. Moreover, we found asymmetries in the conditional correlations in both WTI crude oil and copper futures markets but not in Soya Bean. This indicates that the conditional correlations in these two markets react to joint bad news more strongly than to the joint good news[3] of the same magnitude.

Furthermore, the findings from the portfolio constructions in our study indicate interesting results for investors. First of all, findings in Geman and Khaorubi (2008) are confirmed for pre-2008 period. In other words, an investor can enjoy the benefit of using an 18-month maturity futures contract over a 1-month maturity one by obtaining lower volatility with higher return from his/her investment. However, this benefit seems to have vanished in post 2008 period for both WTI and Soya bean futures but surprisingly not for Copper futures. Moreover, the diversification benefit brought into a traditional portfolio of stocks by commodity futures (short and/or long maturity) seems to have vanished for WTI; but not for Copper or Soya bean in post-crisis period. Hence, investors should consider using copper and soya bean futures curves in their portfolio as they can still enhance their portfolio returns even in the post-2008 period, which also indicates their usefulness in periods of turmoil. Secondly, our results indicate that much of the benefits of using a distant maturity futures contract come from its significantly lower volatility and higher return in comparison to short maturity one; not because of the difference in its dependence structure to the stock market. Here, we also can confirm the Samuelson (1965) hypothesis that the volatility of futures contracts increases as it approaches expiration. Moreover, an investment in a shorter-dated contract is more sensitive to transitory events that affect the underlying commodity (Bienkowski, 2010) and hence an investor can avoid the exposure to these transitory risks by using distant maturity futures contract. Last but not least, our traditionally compiled 18-month[4] maturity futures contract series also confirms the benefit of using constant maturity futures contract over traditional long and hold futures series;

[3] Here the joint bad news (the joint good news) indicates that the futures price of both stocks and commodities goes down (up). (Cappiello et. al., 2006)

[4] 11-month maturity for Soya bean futures.

where former one has much higher volatility and similar return. This indicates that an investor will be better off using a constant distant-maturity futures contract than holding a long-maturity futures contract till its expiration. Overall, our results indicate that investors can still enjoy the benefits of portfolio diversification by using Copper or Soya Bean futures curves, or both, despite to the fact that the correlations between stocks and commodity futures have increased.

The remainder of the chapter is organized as follows. The next section presents the literature on increased correlation between commodity futures returns and stock returns, and the reasons behind this increase. Section 2.3 describes the methodology used to estimate conditional correlations and to construct portfolios between each commodity futures and stock returns. Section 2.4 presents data, and descriptive statistics and Pearson's correlations of constant maturity time series. In Section 2.5 the empirical findings are discussed. A conclusion is given in the final section.

2.2 Literature Review

Many studies with data periods that ended before 2008 have indicated the diversification benefits of adding commodities to traditional assets and bonds portfolios. Gorton and Rouwenhorst (2006) is one of these studies that analysed the stylized facts of commodity futures after 2000s. An Index of commodity futures covering the period between July 1959 and December 2004 is constructed by them to use in their analysis. They found that the standard deviation of commodity futures returns is lower than that of stocks and bond returns. Moreover, it is found that the negative correlation between returns of commodity futures and stocks, and bonds tend to increase with holding period. Chong and Miffre (2010) analysed the conditional return correlation between commodity futures and traditional assets, such as global equities and fixed income securities where they used returns of 25 commodities futures, 7 equity indices and 6 bond indices. They used GARCH (1, 1) model for volatility estimations and Dynamic Conditional Correlation (DCC) model to estimate conditional correlations between commodity futures and traditional assets. They found that the return correlations between the S&P 500 and commodity futures fell over time, indicating that commodity futures have become better tools for asset allocation. Buyuksahin et al. (2010) examined if the prices of, and the returns on passive investments on commodities and equities move in sync and whether the intensity of this co-movement increased over time. Overall using dynamic correlation and recursive cointegration techniques they found no persistent increase in co-movements between the returns on passive commodity and equity investments over the last 17 years.

However, most of the recent studies argued that the correlation between return of commodities and equities has increased, and studied the implication of this increase on portfolio diversification. Delatte and Lopez (2013) used a copula based approach to investigate the dependence structure between commodities and equities. Two major commodity indices SP-GSCI and DJ-UBS, and their sub-indices, and major equity indices (SP500, FTSE100, CAC40 and DAX30) for the period of January 1990 to February 2012 are used in their analysis. First, they found that dependence between returns of commodities and equities is time varying, symmetric and occurs most of the time. Secondly, not allowing for time varying parameters in the dependence distribution produces a bias towards evidence of tail dependence. And lastly, they found that the co-movement between commodities and stock markets became stronger starting in September 2008 with the bankruptcy of Lehman brothers and the strengthening of the financial crisis. Daskalaki and Skiadopoulos (2011) investigated that if investors are better off by including commodities in their traditional portfolio assets. They used monthly closing prices of the S&P 500 Total Return Index, Barclays US Aggregate Bond Index and the Libor 1-month rate to proxy equity market, bond market and risk-free rate, respectively. Moreover, they use S&P GSCI and DJ-UBSCI total return indices and five individual futures contracts on crude oil, cotton, copper, gold and live cattle for the period of January 1989 to December 2009. First, they employed a mean-variance and non-mean variance spanning tests within an in-sample setting. Second, they formed optimal portfolios by taking into account higher order moments of portfolio returns distributions. Then, they investigated the out-of sample performance. It is found that between the in-sample settings the commodities do not have diversification benefits to MV investors while do have for non-MV investors. However, these benefits are not found for the out-of sample settings. Most of the time traditional assets without commodities had better performance.

Some of these recent studies analysed the reasons behind this increased correlation between returns of commodities and equities. Buyuksahin and Robe (2014) used a non-public dataset of daily individual trader positions in 17 US commodity and equity futures markets between July 2000 and March 2010, and showed that the correlation between rate of returns on equities and commodities are higher when there is high hedge funds participation in the market (especially funds that trade on both equity and commodity markets). Sivennoinen and Thorp (2013) studied the gradual changes in correlations between stocks, bonds and commodity futures returns driven by observable financial variables and time. They search for evidence of a closer financial integration between commodities futures returns and traditional asset returns, and test the hypothesis that the connection is not affected by financialization. They use Wednesday log returns to futures contracts on 24 commodities from May 1990 to July 2009. By using a DSCC-GARCH (Double Smooth Transition Conditional Correlation) correlation model, where they use time and VIX as transition variables, they found that increases in VIX index are linked to higher commodity-stock correlation. Moreover, Tang and Xiong (2012) studied the increased correlation among commodities themselves. The data starts as early as 1959 and ends in 2008, with some variation across commodities according to data availability. Some of the commodities are included in the S&P GSCI index, some in DJ-UBS and some of them in neither of the indices. They found that the return correlations of a broad set of non-energy commodities with oil were small before 2004, which is consistent with the finding of Erb and Harvey (2006), however steadily increased since then. Overall, they found that prices of non-energy commodities become increasingly correlated with oil prices and in fact this trend is more significant for commodities in the two popular S&P GSCI and DJ-UBS indices suggesting increased Index investing in financialization of commodities.

Geman and Kharoubi (2008) argued that the choice of the Future maturity is a key issue to get the most benefits from commodity futures investing. They studied the diversification benefits of crude oil futures contracts, where they analysed the time-to-maturity effect of the WTI crude oil futures on portfolio diversification by using copula functions. They found that stocks and crude oil futures have a negative dependency regardless of the maturity. The dependence parameter increases when oil markets goes up (down) and stocks markets goes down (up), whereas it is flat when both markets move in a synchronous manner. In fact, this observation is more pronounced in the case of most distant maturities i.e. 18-month futures and hence argued that distant month futures leads to an excellent diversification effect in both the upward and downward trending equity markets. Hence the investors can avoid too frequent rolls of the position.

2.3 Conditional Correlation and Portfolio Construction

2.3.1 Dynamic Conditional Correlations

Most of recent studies, such as Buyuksahin and Robe (2014), Buyuksahin et al. (2010), Miffre and Perez (2012), and Chong and Miffre (2010), used Engle (2002)'s DCC

(Dynamic Conditional Correlation) model to analyse correlations between the return of commodities and traditional assets. Geman and Kharoubi (2008) studied the empirical dependence between returns of WTI futures curve and S&P 500 Index using copula functions developed by Fermanian and Scaillet (2003), who extended the kernel method to the bivariate case.

In this study we employ Engle (2002)'s DCC model, which is a direct generalization of Constant Conditional Correlation (CCC) model of Bollerslev (1990), to estimate the time-varying conditional correlations between logarithmic returns of Soya bean futures curves and S&P 500 Index. This methodology, as reported in Huang and Zhong (2010), outperforms other unconditional techniques such as rolling correlations or exponential smoothing; as the inferences about the true nature of the relationship between variables are restricted by the sensitivity of the estimated correlations to volatility changes and the times of high volatility only increases the concerns of heteroscedasticity biases (Forbes and Rigobon, 2002). The model assumes that the k x 1 vector of returns r_t is conditionally normally distributed with zero mean and covariance matrix H_t ;

$$r_t = \ |\mathcal{F}_{t-1} \sim N(0, H_t) \tag{2.1}$$

where $\mathcal{F}_{t-1}$ is the information set at time $t-1$[5]. The covariance matrix H_t can be decomposed to $H_t = D_t P_t D_t$, where $D_t = diag\{\sigma_{it}\}$ is the k x k diagonal matrix with i^{th} diagonal element corresponding to the conditional standard deviation of the i^{th} asset from univariate GARCH models and $P_t = \{\rho_{ij,t}\}$ is the time varying correlation matrix. As the DCC model is designed to allow for two stage estimation of the conditional covariance matrix, in the first stage univariate GARCH models are estimated for each residual series,

[5] The standard error of the model does not depend on the choice of filtration (ARMA, demeaning etc.) (Engle and Sheppard, 2001), hence the return series are filtered by an AR (1) model, $r_t = \emptyset_1 r_{t-1} + \epsilon_t$.

and in the second stage, residuals from the return series, transformed by their standard deviation that are estimated during the first stage, are used to estimate the parameters of dynamic correlation. In this study a GARCH (1, 1) model is selected according to Bayesian Information Criterion (BIC) to estimate the time-varying conditional variances:

$$h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1} \tag{2.2}$$

Once the univariate volatility model is estimated, the standardized residuals $\varepsilon_{it} = r_{it}/\sqrt{h_{it}}$ are used to estimate the correlation parameters. For the time-varying correlation estimates between commodity futures returns and the S&P 500 Index Futures returns a DCC (1 ,1) model is chosen, also according to BIC, which is given by;

$$Q_t = (1 - a - b)\bar{P} + a\varepsilon_{t-1}\varepsilon_{t-1}' + bQ_{t-1} \tag{2.3}$$

$$P_t = Q_t^{*-1}Q_tQ_t^{*-1} \tag{2.4}$$

where $\bar{P} = E[\varepsilon_t\varepsilon_t']$ is the unconditional correlation matrix of standardized residuals ε_t and, a and b are scalars such that $a + b < 1$. $Q_t^* = [q_{iit}^*] = \left\lfloor\sqrt{q_{iit}}\right\rfloor$ is a diagonal matrix with the square root of the i^{th} diagonal element of Q_t on its ith diagonal position. As long as Q_t is positive definite, Q_t^* is a matrix which guarantees $P_t = Q_t^{*-1}Q_tQ_t^{*-1}$ is a correlation matrix with ones on the diagonal and every other element ≤ 1 in absolute value. Hence, the conditional correlation between asset i and j at time t can be written as $\rho_{ij,t} = \frac{q_{ij,t}}{\sqrt{q_{ii,t}q_{jj,t}}}$. The estimations are done by the maximum-likelihood methodology.

Cappiello et al. (2006) developed a new GARCH process, called asymmetric generalized dynamic conditional correlation (AG-DCC), where they generalized the previous DCC model by allowing for series specific news impact and smoothing parameters, and for conditional asymmetries in correlation dynamics. And therefore the AG-DCC model is suitable for analysing the hypothesis that correlation might be higher after a negative innovation than after a positive one of the same magnitude. The model given in Equation (2.5) below is used in our study to estimate the asymmetries in conditional correlations between WTI and Copper futures curves and S&P 500 Index.

$$Q_t = (\bar{P} - a^2\bar{P} - b^2\bar{P} - g^2\bar{N}) + a^2\varepsilon_{t-1}\varepsilon_{t-1}' + g^2 n_{t-1}n_{t-1}' + b^2 Q_{t-1} \qquad (2.5)$$

where $n_t = I_{[\varepsilon<0]} \odot \varepsilon_t$, with $I_{[\varepsilon<0]}$ being a k x 1 indicator function, which takes on the value 1 when $\varepsilon_t < 0$ and 0 otherwise. $\bar{N} = E[n_t n_t']$ is the unconditional covariance matrix of n_t .The term $n_{i,t}n_{j,t}$ will be nonzero if both indicators are equal to 1 or when both returns happen to be negative (joint bad news). The asymmetry therefore implies a higher correlation coefficient after joint bad news than after joint good news. The positive semi-definiteness of the matrix in parentheses is a sufficient condition for Q_t to be positive definite. This holds by the condition that $a^2 + b^2 + \delta g^2 < 1$, where $\delta = maximum\ eigenvalue\ [\bar{P}^{-\frac{1}{2}}\bar{N}\bar{P}^{-\frac{1}{2}}]$.

2.3.2 Portfolio Construction

We construct portfolios using returns of S&P 500 Index and each commodity futures curves with different weights assigned on the portfolio components. The modern portfolio theory indicates that the return of a portfolio is given by;

$$R_p = \sum_{i=1}^{N} w_i R_i \qquad (2.6)$$

where $\sum_{i}^{N} w_i = 1$ is the weight of the assets in a portfolio. In our analysis each portfolio construction has two assets; asset 1 is the return on S&P 500 Index and asset 2 is the return on different maturity futures of each three commodities. The weights are allocated as; 100% S&P 500 Index; 90% S&P 500 Index and 10% commodity futures[6]; 80% to 20%; and finally 60% to 40%. Hence, we are able to observe the individual effect of adding commodity futures with different maturities to the portfolio of stocks in terms of return and volatility. The variance of a portfolio is computed as;

$$\sigma_p^2 = \sum_{i,j=1}^{N} w_i w_j \, CovR_i R_j = \sum_{i=1}^{N} w_i^2 \, Var(R_i) + \sum_{i,j=1, i \neq j}^{N} w_i \, w_j Cov(R_i, R_j) \qquad (2.7)$$

The variance of each asset is computed by a univariate GARCH (1, 1) model, while the conditional covariance matrices are computed by AG-DCC or DCC model. We choose the AG-DCC (for WTI and Copper market) model if the asymmetric term (g^2) in the equation (2.5) is significant and DCC (for Soya Bean market) model otherwise to estimate the conditional covariance matrices that are used in portfolio constructions. This is also an important aspect of our analysis as we use time-varying conditional covariances for portfolio constructions in comparison to literature where simple standard deviations and Pearson's correlation are used.

2.4 Data and Descriptive Statistics

2.4.1 Data

The data employed for this study is collected from the DataStream. We use daily settlement futures prices of WTI Crude Oil and Copper contracts from August 1995 to

[6] Different maturities of each commodity are used individually in portfolio constructions.

May 2012, and the daily futures prices of Soya bean contracts from August 1995 to July 2012. We choose Copper from metals group because it is one of the most popular industrial metals used in everything from circuit boards to plumbing. Demand from emerging economies such as China and India moves prices making it a volatile commodity perfect for trading. The Soya bean from agricultural group is chosen because it is one of the most important beans in the world. It has a negative impact on other grains which leads extreme fluctuations in the price, a perfect environment for trading. The price of 1- month, 3- month, 6- month, 12- month and 18- month maturity contracts are used for WTI crude oil and Copper to construct the futures curve, while the price of 1- month, 3- month, 7- month and 11- month maturity contracts are used for Soya bean to construct the futures curve [7]. Moreover, we constructed a traditional long and hold futures price series where the futures contract is kept until maturity. We constructed this price series for 18-month futures contract in WTI and copper, and for 11-month futures contract in Soya Bean futures market. The S&P 500 Index is used as a proxy for a diversified stock portfolio and its daily prices for the same periods as the corresponding commodities are used. Furthermore, we compiled trading volumes of WTI Crude Oil futures curves for discussion of results purposes. The analysis will be conducted in full sample and in two successive sub-samples. The data is cut into sub-sample periods at September 2008 so that we are able to examine the effects of 2008 financial crisis on the correlation between the futures curves of commodities and S&P 500 Index. The number of observations are given in Table 2.1 and as follow; the daily returns of WTI crude oil futures is $T = 4359$ for whole sample with $T_1 = 3408$ in pre-crisis period and $T_2 = 951$ in post-crisis period; Copper futures $T = 4348$ in whole period with $T_1 = 3390$ and $T_2 = 958$; and Soya bean futures we have

[7] Soya Bean futures have contracts for January, March, May, July, August, September and November whereas WTI and Copper futures have contracts for every calendar months (www.cmegroup.com). Hence, 6-month, 12-month and 18-month futures contracts for the Soya Bean are not available.

$T = 4419$ with $T_1 = 3408$ and $T_2 = 1011$. The numbers of observations in S&P 500 Index series are same as the corresponding commodities that they are analysed with. The returns are calculated as changes in logarithms of the price series in our analysis.

Following Geman and Kharoubi (2008), we use daily futures prices for five maturities to construct the futures curves. At a given date, the prices of futures contracts with the five maturities are collected and sorted by time-to-maturity in ascending order. Hence a matrix of futures price data is constructed whose rows display the complete futures curve for the given date. In other words, at a given date the different maturity price series give the complete forward curve look. The construction of different maturity price series differs in this chapter in comparison to first chapter where the different maturity series belong to one specific contract and the historical prices of that contract were collected. In this chapter, the different maturity price series are prices on a given date and they do not necessarily belong to the same contract. For example, if prices of January 2012 contract are taken as 1-month maturity price series then prices of April 2012 contract are collected as 3-month maturity series and so on. Moreover, the daily prices of S&P 500 Index are used as a proxy for diversified stock portfolio.

2.4.2 Descriptive Statistics

Tables 2.2 to 2.4 display the descriptive statistics for return series of the three commodity futures and S&P 500 Index. In Table 2.2 the descriptive statistics of daily returns of WTI Crude Oil futures curves and S&P 500 Index are shown for whole period and for two sub-sample periods, respectively. The results indicate that 18-month maturity crude oil futures has lower volatility and higher return than a nearby futures contract in whole sample period. This is also true in first sub-sample period. However, in the second sub-sample, which covers the 2008 financial crisis, we find that 18-month maturity generates more negative return than other nearby futures, though it is still less volatile than other maturities. Compared with return of S&P 500 Index, the returns of Crude Oil Futures are more volatile and higher, except for the second sub-sample period where average return of S&P 500 Index is positive whereas average return of the WTI futures curves are negative. These findings are in favour of Geman and Kharoubi (2008) as they also pointed out that return on a distant-month crude oil futures contract is less volatile than a nearby futures contract. They indicated that the nearby futures contract is a standard proxy for the spot price and therefore is traded extensively as an investment vehicle for hedge fund activities.

The descriptive statistics of daily returns of Copper and Soya bean Futures in comparison to S&P 500 Index are shown in Table 2.3 and Table 2.4, respectively. The results indicate that Copper futures curves returns have a similar profile to Crude Oil in that the distant-maturity futures are less volatile and have higher mean return than the nearby futures contracts. When compared with return of S&P 500 Index, Copper futures are more volatile and have higher returns. The Soya bean futures returns have a slightly different profile from the other two commodities: 11-month Soya bean futures have a lower mean return than nearby futures, although the volatility is also less than the nearby ones. In general, the results show that all of three commodity markets and equity market suffered from higher volatility and lower returns after the 2008 financial crisis, which is in favour of the findings of Wen et al. (2012) where they studied the contagion between energy and stock market. The results for traditionally constructed futures series (18-month* for crude oil and copper, and 11-month* for Soya bean) are shown in the last row of Tables 2.2 to 2.4. It is clear that they have higher volatility than their counterparts in all three commodity markets.

Table 2.6 exhibits Pearson's correlation coefficients between returns of each commodity futures curve and S&P 500 Index for whole period and two sub-sample periods.

First of all, it can be seen that correlation is much higher in post-crisis period in comparison to pre-crisis, confirming the so-called increasing correlation after 2008 financial crisis from unconditional correlation perspective. Secondly, the results are in favour of Geman and Khaorubi (2008) from futures curve perspective that the distant month maturity contract has higher correlation than a front month one for all commodities. Last but not least, traditionally constructed 18-month maturity contract has lower correlation than all other maturities in most cases.

2.5 Empirical Results

In the first stage of DCC model building we filter the logarithmic return series using an AR (1) model. Then, these residuals from each commodity futures curves and S&P 500 Index are used to estimate the univariate GARCH specifications. Cappiello et al. (2006) argues that to be able to estimate the conditional correlations consistently, the univariate GARCH models have to be specified properly. Hence, the lag length of the GARCH model is chosen according to Bayesian Information Criterion (BIC). In our analysis a GARCH (1, 1) process is selected and the findings for the estimated parameters are given in Appendix Table 2.13 for the daily returns of WTI Crude Oil, Copper and Soya bean futures series as well as S&P 500 Index. The results show that the parameters α and β are both statistically significant different from zero and the constraint that $\alpha + \beta < 1$ is satisfied. The estimated conditional correlation parameters are also given in Appendix in Table 2.14. The AG-DCC results shows that the asymmetric effect in the conditional correlations is present for WTI Crude Oil - S&P 500 Index and Copper - S&P 500 Index pairs along futures curve but not for Soya Bean. Hence, we chose a DCC (1, 1) model for Soya Bean futures and AG-DCC (1, 1, 1) model for WTI and Copper futures according to BIC.

The estimated dynamic conditional correlations between each of commodity futures curves and S&P 500 Index are plotted in Figures 2.1 to 2.3. We compare dynamic conditional correlations between 18-month (11-month for Soya Bean) maturity futures and S&P 500 Index to other maturity futures contracts in subplots. The results indicate that there is an increasing trend in all commodity futures curves which has started well before 2008 financial crisis. For example, in WTI crude oil market correlations were mean reverting before 2002, but since then an increasing trend seems to start. In Copper market the trend seems to have started in early 2006 and in Soya Bean market as early as 1997. In addition, it is also observed that there is a sharp increase in correlations between commodity futures and S&P 500 Index after the 2008 financial crisis, which is in line with findings of Buyuksahin and Robe (2014).

The results of WTI futures in Figure 2.1 show that there is not a significant difference in the correlations between S&P 500 Index and commodity futures across different maturities for most of the time, except for a very short period in the mid-2011 where short-term maturity futures have lower correlations with S&P 500 Index than 18-month one. In addition, the final graph in Figure 2.1 depicts correlations between S&P 500 Index and 18-month constant maturity, and between S&P 500 Index and 18-month traditionally constructed (long and hold) futures. No significant difference between these two series of correlations is observed. The results for Copper market are similar to those in WTI market: there is no significant difference between short-maturity and long-maturity futures series or between 18-month constant maturity futures and the traditionally constructed one in terms of their correlations with S&P 500 Index. Soya Bean markets show some difference in comparison to WTI and copper market. For example, short maturity futures seem to have lower correlation with S&P 500 Index especially in post-crisis period than 11-month maturity futures. However, the magnitude of the difference is around 0.05, which is quite small. Moreover, the difference between 11-month constant maturity futures and traditional futures series is also visible after 2008 period, but again with a small magnitude. Overall, the conditional correlations between commodity futures curves and S&P 500 Index have similar patterns across different maturities in all of the three markets considered in our study. This can be seen clearly in Figure 2.4; where we plot conditional correlations of different maturities of each commodity in one graph.

In the next stage, portfolios containing S&P 500 Index and commodity futures with different maturities are constructed. This allows us to observe the benefits of using a distant-month maturity futures contract over a nearby futures contract or a traditional buy and hold futures contract. We also vary the weights assigned to the portfolio components so that we can have a complete view of the diversification benefits brought by the commodity futures. The portfolio returns and volatilities are calculated for the entire sample period and for pre and post crisis period as well as the Sharpe ratios. The results for WTI Crude Oil, Copper and Soya bean futures are given in Table 2.7 to 2.12.

Table 2.7 shows that portfolios containing an 18-month WTI crude oil futures contract produce lower volatility and higher return when compared to their counterparts containing a 1-month WTI crude oil futures contract. This is true for the first sub-sample period prior to September 2008 and this observation is consistent with the finding of Geman and Kharoubi (2008). Moreover, diversified portfolios containing oil futures produce higher average return and lower volatility in comparison to portfolio consisting of only S&P 500 Index, which is also true for pre-crisis period. However, in post-crisis period, adding 18-month futures contracts to the traditional stocks portfolio does not produce higher return in comparison to 1-month maturity. In fact, diversified portfolios consisting of both oil futures and S&P 500 Index do not provide higher return than only stock portfolios either. These results are also confirmed in Table 2.8 where it can be seen that the Sharpe ratio of 18-month maturity futures is the highest in pre-crisis period whereas the opposite is true in post-crisis period. This indicates that not only benefit of using distant-maturity contract over nearby maturity vanishes also the diversification benefit of using any maturity WTI futures contracts vanishes in post-crisis period. The above results are also confirmed with weekly[8] data in the crude oil market.

The results from copper futures markets in Table 2.9 are quite interesting. Different from the WTI crude oil futures market, the diversification benefit brought by a distant month maturity futures in comparison to a front month one is present not only in the pre-crisis period but also in the post crisis period. Hence, an investor can still enjoy the benefits of diversification using Copper futures contracts in his/her portfolio where he/she can obtain higher return and lower volatility compared to pure stocks portfolio as well as can enhance his/her return using 18-month constant maturity futures contract. For example, an investor would be better off with a return of 0.0109% with 1.54% volatility in comparison to 0.0100% return with 1.60% volatility if he/she uses 18-month constant maturity contract instead of investing 100% in S&P 500 Index in post-crisis period. The Sharpe ratio results in Table 2.10 also shows that 18-month maturity futures has the highest ratio in both pre and post-crisis period. What is more is that the Sharpe ratio increases with the weight of Copper futures added to the traditional stock portfolio. It indicates that an investor would get a higher Sharpe ratio with a portfolio of 60% S&P 500 Index and 40% Copper futures in comparison to a portfolio of 90% S&P 500 Index and 10% Copper futures.

Soya Bean futures also have interesting results in Table 2.11. The benefit of using a distant-constant maturity over a short-constant maturity or traditionally compiled long-maturity futures is present in pre-crisis period; while it vanishes completely in post-crisis period. However, the diversification benefit brought into traditional stocks still remains in

[8] The results for the weekly returns are available on request.

post-crisis period. For example, an investor would be still better off using Soya bean short-maturity futures in his/her portfolio than investing 100% in stocks portfolio. The Sharpe ratio results of Soya bean futures curves given in Table 2.12 also indicates that 11-month maturity futures have the highest ratio in pre-crisis period but this reverses in post-crisis period. Moreover, it should also be noted that similar to Copper futures the more percentage of portfolio given to Soya bean futures the higher the Sharpe ratio is. Overall, a distant constant maturity futures contract is better in terms of producing higher return and lower volatility than a short maturity futures contract or a traditionally constructed long and hold futures in pre-crisis period for all three commodities studied, but it vanishes for WTI and Soya bean in post-crisis period and remains for Copper futures.

Last but not least, our analysis shows that in spite of the fact that distant-maturity futures contracts have similar or even higher correlations with S&P 500 Index in comparison to a nearby futures contract, they still bring positive diversification benefits to portfolio of stocks. It is also observed that these benefits come from the fact that long-constant maturity futures have significantly lower volatility and somewhat higher return than the short-maturity ones, not because of the differences in their correlation with return of S&P 500 Index. It should be noted that the trading volume is thinner in longer maturity futures in comparison to shorter maturity ones as shown for WTI Crude Oil in Table 2.5 and this might cause some liquidity issues. However, investors can still enjoy these found benefits by using 3-month or 6-month futures instead of 1-month maturity one as it can be seen that these benefits increase with maturity and present in these fairly liquid maturities.

2.6 Conclusion

This paper adds to the recent literature in increased correlation between commodities and equities through analysing the dependence from a term structure of commodity futures perspective. Over the recent years there have been many studies that examined the linkages between these two markets because of its importance in portfolio diversification. Recent studies, especially those whose data sample covers the period after 2008 concluded that the dependence between these two markets have substantially increased to a point that the value of diversification is now vanished. However, most of the studies used the commodity index futures for their analysis. Although there are some studies that use individual commodities, none of them studied the futures curves of commodities for the post 2008 financial crisis period. This study tries to fill this gap by looking at the correlations between commodities and equities from the perspective of futures curves in three markets, i.e. energy; metal and agricultural, and its impact on portfolio diversification.

We further studied the maturity effect on the dependence between three individual commodity futures curves (WTI, Copper and Soya Bean, hence representing the energy, metal and agricultural markets) and the S&P 500 Index by using the methodology of DCC (Engle, 2012) and AG-DCC (Cappiello et al., 2006). The results show that the estimated conditional correlations between futures curves of each commodity and S&P 500 Index have similar patterns across different maturities in WTI crude oil and copper markets. Specifically, there is no significant difference in the correlations either between short-maturity and long-maturity futures series or between 18-month constant maturity futures and the traditionally constructed long and hold 18-month futures contract in the WTI crude oil or in the copper market. Short-month maturity futures have lower correlations with S&P 500 Index in comparison to distant-month maturity futures in the post-2008 period, but the magnitude is quite small to consider.

Portfolios containing S&P 500 Index and commodity futures with different maturities and weights show interesting results. First of all, we find that an investor would be better off using a distant-constant month maturity WTI crude oil futures in his/her portfolio than a nearby futures one in terms of reducing volatility and increasing return of his/her investment. This is in line with the results of Geman and Khaorubi (2008). However, it is observed in post-crisis period this benefit completely vanishes. Moreover, results indicate that crude oil futures have lost its importance as a diversification tool in post-crisis for all maturities as one would be better off investing 100% in stocks portfolio. Different from WTI crude oil futures, diversified portfolios containing Copper or Soya Bean futures are found to produce higher return and lower volatility compared to a 100% stocks portfolio even in the post crisis period. Moreover, the benefit of using a distant-constant maturity futures contract is present and enables an investor to enjoy higher return with lower volatility in comparison to using a nearby futures contract or traditionally compiled (long and hold) futures in both pre and post-crisis period for Copper, but only in pre-crisis period for Soya bean. Overall, copper futures seem to be the best commodity to use for portfolio diversification purposes, because the distant-maturity futures produce higher return and much lower volatility than its short-maturity counterpart and other two commodities even in post-crisis period where it is much needed.

Overall, our contributions to the literature on increased correlation between the returns of commodities and equities are as follow: First, we study this hypothesis of increased correlation and confirm it from a term structure of commodity futures curve perspective. Second, by extending the study of Geman and Khaorubi (2008) we are able to observe the effects of the 2008 financial crisis and found that the benefits of adding crude oil futures to the traditional stocks portfolio has vanished although this is not the case for Copper or Soya Bean futures. Last but not least, we confirm the benefit of using 18-month constant-maturity futures in comparison to traditionally constructed 18-month buy and hold futures contract. This is an important feature for investors to consider as they would be enjoying lower volatility and higher return with a distant-constant maturity futures contract.

Table 2.1 Number of Observations

This table indicates the total number of observations for each different maturity time series as well as numbers of pre and post-crisis observations that are used in our research. There are five different time series for WTI Crude Oil and Copper markets with maturity of 1-month, 3-month, 6-month, 12-month and 18-month, while four time series for Soyabean futures markets with maturity of 1-month, 3-month, 7-month and 11-month.

	WTI Crude Oil	Copper	Soyabean
Pre-Crisis Period	3,408	3,390	3,408
Post-Crisis Period	951	958	1,011
Total	4,359	4,348	4,419

Table 2.2 Descriptive Statistics: WTI Crude Oil futures and S&P 500 Index

This table shows the descriptive statistics of daily logarithmic returns of six constant maturity WTI Crude Oil futures and S&P 500 Index for the period between August 1995 and May 2012. Panel (a) gives results from full period; while panel (b) and panel (c) are for pre-crisis and post-crisis period, respectively.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

	Mean (%)	**Volatility (%)**	**Maximum**	**Minimum**	**Skewness**	**Kurtosis**	**Jarque-Bera**	**Probability**
Panel (a): Full period (August 1995-May 2012)								
Crude oil 1-mo. Futures	0.0403	2.42	0.16	-0.17	-0.14	7.22	3251.33	0.00
Crude oil 3-mo. Futures	0.0411	2.04	0.12	-0.12	-0.22	6.00	1672.61	0.00
Crude oil 6-mo. Futures	0.0413	1.82	0.10	-0.13	-0.30	6.78	2660.53	0.00
Crude oil 12-mo. Futures	0.0412	1.59	0.10	-0.09	-0.24	6.24	1946.23	0.00
Crude oil 18-mo. Futures	0.0405	1.48	0.10	-0.09	-0.25	6.24	1957.34	0.00
Crude Oil 18-mo. futures*	0.0407	2.12	0.41	-0.40	-1.45	89.35	1355320.00	0.00
S&P 500 Index	0.0207	1.22	0.13	-0.10	-0.09	12.25	15556.27	0.00
Panel (b): Pre-crisis period (August 1995-September 2008)								
Crude oil 1-mo. Futures	0.0549	2.26	0.14	-0.17	-0.27	6.22	1519.06	0.00
Crude oil 3-mo. Futures	0.0557	1.89	0.12	-0.12	-0.17	5.34	792.20	0.00
Crude oil 6-mo. Futures	0.0560	1.66	0.09	-0.13	-0.29	6.51	1793.28	0.00
Crude oil 12-mo. Futures	0.0560	1.43	0.07	-0.09	-0.16	4.92	537.47	0.00
Crude oil 18-mo. Futures	0.0558	1.33	0.06	-0.08	-0.18	4.95	559.20	0.00
Crude Oil 18-mo. futures*	0.0557	1.93	0.21	-0.40	-4.95	105.27	1498594.00	0.00
S&P 500 Index	0.0243	1.12	0.06	-0.08	-0.12	6.71	1963.86	0.00
Panel (c): Post-crisis period (September 2008-May 2012)								
Crude oil 1-mo. Futures	-0.0120	2.92	0.16	-0.13	0.12	7.64	856.27	0.00
Crude oil 3-mo. Futures	-0.0115	2.52	0.12	-0.10	-0.24	5.85	331.41	0.00
Crude oil 6-mo. Futures	-0.0114	2.31	0.10	-0.10	-0.25	5.78	316.29	0.00
Crude oil 12-mo. Futures	-0.0121	2.08	0.10	-0.09	-0.26	5.91	346.59	0.00
Crude oil 18-mo. Futures	-0.0144	1.93	0.10	-0.09	-0.26	5.94	353.29	0.00
Crude Oil 18-mo. futures*	-0.0132	2.70	0.41	-0.13	3.28	58.21	122373.90	0.00
S&P 500 Index	0.0076	1.60	0.13	-0.10	-0.04	11.78	3054.23	0.00

Table 2.3 Descriptive Statistics: Copper futures and S&P 500 Index

This table shows the descriptive statistics of daily logarithmic returns of six constant maturity Copper futures and S&P 500 Index for the period between August 1995 and May 2012. Panel (a) gives results from full period; while panel (b) and panel (c) are for pre-crisis and post-crisis period, respectively.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

	Mean (%)	Volatility (%)	Maximum	Minimum	Skewness	Kurtosis	Jarque-Bera	Probability
Panel (a): Full period (August 1995-May 2012)								
Copper 1-mo. Futures	0.0243	1.86	0.12	-0.12	-0.29	7.24	3315.85	0.00
Copper 3-mo. Futures	0.0244	1.81	0.12	-0.12	-0.24	7.03	2986.89	0.00
Copper 6-mo. Futures	0.0253	1.73	0.12	-0.11	-0.20	7.32	3407.47	0.00
Copper 12-mo. Futures	0.0272	1.64	0.11	-0.11	-0.18	7.62	3886.47	0.00
Copper 18-mo. Futures	0.0284	1.62	0.11	-0.11	-0.17	7.57	3805.29	0.00
Copper 18-mo.futures*	0.0284	1.75	0.11	-0.17	-0.69	11.43	13204.56	0.00
S&P 500 Index	0.0210	1.22	0.13	-0.10	-0.09	12.22	15415.28	0.00
Panel (b): Pre-crisis period (August 1995-September 2008)								
Copper 1-mo. Futures	0.0279	1.69	0.11	-0.12	-0.38	7.69	3190.58	0.00
Copper 3-mo. Futures	0.0277	1.62	0.12	-0.12	-0.28	7.13	2450.70	0.00
Copper 6-mo. Futures	0.0286	1.52	0.11	-0.11	-0.22	7.23	2552.98	0.00
Copper 12-mo. Futures	0.0306	1.41	0.11	-0.09	-0.15	7.37	2705.47	0.00
Copper 18-mo. Futures	0.0318	1.39	0.11	-0.09	-0.13	7.12	2401.50	0.00
Copper 18-mo.futures*	0.0325	1.55	0.11	-0.17	-1.10	15.88	24095.41	0.00
S&P 500 Index	0.0241	1.12	0.06	-0.08	-0.12	6.69	1927.27	0.00
Panel (c): Post-crisis period (September 2008-May 2012)								
Copper 1-mo. Futures	0.0119	2.37	0.12	-0.12	-0.15	5.48	248.18	0.00
Copper 3-mo. Futures	0.0125	2.36	0.12	-0.12	-0.16	5.41	236.63	0.00
Copper 6-mo. Futures	0.0132	2.34	0.12	-0.11	-0.15	5.47	247.40	0.00
Copper 12-mo. Futures	0.0146	2.27	0.11	-0.11	-0.16	5.52	257.13	0.00
Copper 18-mo. Futures	0.0156	2.24	0.11	-0.11	-0.17	5.59	271.67	0.00
Copper 18-mo.futures*	0.0138	2.33	0.11	-0.11	-0.18	5.58	270.70	0.00
S&P 500 Index	0.0100	1.60	0.13	-0.10	-0.04	11.85	3123.46	0.00

Table 2.4 Descriptive Statistics: Soya bean futures and S&P 500 Index

This table shows the descriptive statistics of daily logarithmic returns of six constant maturity Soya Bean futures and S&P 500 Index for the period between August 1995 and July 2012. Panel (a) gives results from full period; while panel (b) and panel (c) are for pre-crisis and post-crisis period, respectively.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

	Mean (%)	Volatility (%)	Maximum	Minimum	Skewness	Kurtosis	Jarque-Bera	Probability
Panel (a): Full period (August 1995-July 2012)								
Soya bean 1-mo. Futures	0.0229	1.67	0.07	-0.26	-1.87	25.97	99723.16	0.00
Soya bean 3-mo. Futures	0.0216	1.57	0.07	-0.21	-1.01	14.60	25531.08	0.00
Soya bean 7-mo. Futures	0.0206	1.45	0.07	-0.12	-0.38	6.95	2976.81	0.00
Soya bean 11-mo. Futures	0.0187	1.32	0.07	-0.10	-0.38	6.98	3017.33	0.00
Soya bean 11-mo.futures*	0.0215	1.57	0.10	-0.28	-2.34	39.31	246736.70	0.00
S&P 500 Index	0.0200	1.22	0.13	-0.10	-0.09	12.21	15622.79	0.00
Panel (b): Pre-crisis period (August 1995-September 2008)								
Soya bean 1-mo. Futures	0.0235	1.62	0.07	-0.26	-2.32	34.33	142423.90	0.00
Soya bean 3-mo. Futures	0.0230	1.51	0.07	-0.21	-1.19	18.39	34444.42	0.00
Soya bean 7-mo. Futures	0.0228	1.38	0.07	-0.12	-0.39	7.36	2789.81	0.00
Soya bean 11-mo. Futures	0.0226	1.24	0.07	-0.10	-0.34	7.14	2493.73	0.00
Soya bean 11-mo.futures*	0.0226	1.52	0.10	-0.28	-2.88	52.02	346013.30	0.00
S&P 500 Index	0.0243	1.12	0.06	-0.08	-0.12	6.71	1963.86	0.00
Panel (c): Post-crisis period (September 2008-July 2012)								
Soya bean 1-mo. Futures	0.0207	1.82	0.07	-0.12	-0.78	7.53	965.92	0.00
Soya bean 3-mo. Futures	0.0168	1.75	0.06	-0.11	-0.59	6.77	656.59	0.00
Soya bean 7-mo. Futures	0.0133	1.66	0.06	-0.07	-0.35	5.77	342.32	0.00
Soya bean 11-mo. Futures	0.0054	1.56	0.06	-0.07	-0.41	6.03	416.25	0.00
Soya bean 11-mo.futures*	0.0179	1.71	0.06	-0.15	-0.99	10.93	2813.81	0.00
S&P 500 Index	0.0056	1.57	0.13	-0.10	-0.04	12.00	3406.78	0.00

Table 2.5 Descriptive Statistics: Trading Volume of WTI Crude Oil Futures Series

This table represents the descriptive statistics of the Trading Volume of WTI Crude Oil futures with five different maturities for the period between August 1995 and May 2012. Panel (a) gives results from full period; while panel (b) and panel (c) are for pre-crisis and post-crisis period, respectively.

	Mean	Median	Volatility	Maximum	Minimum	Skewness	Kurtosis	Jarque-Bera	Probability
Panel (a): Full period (August 1995- May 2012)									
1-month maturity	136,348	85,141	114195	670,082	461	1.22	3.58	1103	0.00
3-month maturity	27,608	19,869	24373	246,952	318	2.11	9.56	10624	0.00
6-month maturity	5,586	2,709	8683	155,700	27	4.79	42.19	284520	0.00
12-month maturity	1,501	350	4172	75,952	0	7.26	78.47	1032730	0.00
18-month maturity	706	17	2731	37,751	0	7.23	69.13	801069	0.00
Panel (b): Pre-crisis period (August 1995-September 2008)									
1-month maturity	93,752	71,398	72840	508,749	461	2.01	6.97	4369	0.00
3-month maturity	19,521	15,561	14529	125,348	318	1.90	8.52	6129	0.00
6-month maturity	3,405	1,980	5652	155,700	27	10.54	207.85	5797316	0.00
12-month maturity	763	200	1734	27,495	0	5.90	55.06	389501	0.00
18-month maturity	482	0	1875	36,667	0	8.97	118.35	1862842	0.00
Panel (c): Post-crisis period (September 2008- May 2012)									
1-month maturity	289,089	295,425	104610	670,082	23,856	-0.27	3.83	37	0.00
3-month maturity	56,606	51,402	29874	246,952	4,045	1.40	6.20	690	0.00
6-month maturity	13,404	8,903	12376	79,491	1,890	2.26	8.61	1982	0.00
12-month maturity	4,148	1,556	7753	75,952	21	3.95	23.69	18694	0.00
18-month maturity	1,506	127	4561	37,751	0	4.45	25.81	22857	0.00

Table 2.6 Pearson's Correlation Coefficients

This table represents Pearson's correlation coefficients between logarithmic daily returns of commodity futures and S&P 500 Index. The first row displays the correlation coefficients for the full sample; while the second and third row shows pre and post crisis period respectively.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

Panel (a): WTI crude oil futures and S&P500 Index			
	Aug1995- May2012	**Aug1995-September2008**	**Sept2008-May2012**
Crude oil 1-mo. Futures	0.1446	-0.0201	0.4339
Crude oil 3-mo. Futures	0.1750	-0.0199	0.5053
Crude oil 6-mo. Futures	0.1839	-0.0201	0.5138
Crude oil 12-mo. Futures	0.1900	-0.0184	0.5120
Crude oil 18-mo. Futures	0.1898	-0.0136	0.5059
Crude oil 18-mo.futures*	0.1746	-0.0004	0.4566
Panel (b): Copper futures and S&P 500 Index			
	Aug1995- May2012	**Aug1995-September2008**	**Sept2008-May2012**
Copper 1-mo. Futures	0.2218	0.1047	0.4096
Copper 3-mo. Futures	0.2307	0.1129	0.4110
Copper 6-mo. Futures	0.2349	0.1127	0.4120
Copper 12-mo. Futures	0.2366	0.1117	0.4098
Copper 18-mo. Futures	0.2344	0.1100	0.4068
Copper 18-mo. futures*	0.2305	0.1116	0.4069
Panel (c): Soya Bean futures and S&P 500 Index			
	Aug1995- May2012	**Aug1995-Sept2008**	**Sept2008-Jul2012**
Soya bean 1-mo. Futures	0.1145	0.0252	0.2895
Soya bean 3-mo. Futures	0.1158	0.0200	0.2974
Soya bean 7-mo. Futures	0.1355	0.0331	0.3221
Soya bean 11-mo. Futures	0.1392	0.0228	0.3408
Soya bean 11-mo.futures*	0.1102	0.0188	0.2897

Table 2.7 Portfolio Diversification Using Daily Returns of WTI Crude Oil Futures Curves

This table presents mean and volatility of each constant maturity portfolios. The return of portfolios is calculated using Equation (2.6) and the volatilities are calculated using Equation (2.7). We use the conditional covariance matrix, estimated by A-DCC model, to calculate volatility of portfolios. Each portfolio is constructed with a constant maturity WTI futures and S&P 500 Index using different weights.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

Portfolios	**Maturity**	**Aug95-May12**		**Aug95-May08**		**Sept08-May12**	
		Mean %	Vol %	Mean %	Vol %	Mean %	Vol %
100% S&P 500 Index		0.0207	1.2231	0.0243	1.1173	0.0076	1.6036
90% S&P 500 Index and 10% WTI Crude Oil Futures	1-month	0.0226	1.1509	0.0274	1.0354	0.0056	1.5661
	3-month	0.0227	1.1428	0.0274	1.0264	0.0057	1.5612
	6-month	0.0227	1.1385	0.0275	1.0228	0.0057	1.5547
	12-month	0.0227	1.1326	0.0275	1.0177	0.0056	1.5456
	18-month	0.0226	1.1304	0.0274	1.0166	0.0054	1.5394
	18-month*	0.0227	1.1483	0.0274	1.0328	0.0055	1.5634
80% S&P 500 Index and 20% WTI Crude Oil Futures	1-month	0.0246	1.1352	0.0304	1.0150	0.0037	1.5676
	3-month	0.0247	1.1048	0.0306	0.9815	0.0038	1.5482
	6-month	0.0248	1.0906	0.0306	0.9678	0.0038	1.5320
	12-month	0.0248	1.0715	0.0306	0.9492	0.0036	1.5110
	18-month	0.0246	1.0644	0.0306	0.9441	0.0032	1.4967
	18-month*	0.0247	1.1174	0.0306	0.9950	0.0034	1.5572
70% S&P 500 Index and 30% WTI Crude Oil Futures	1-month	0.0266	1.1755	0.0335	1.0556	0.0017	1.6068
	3-month	0.0268	1.1118	0.0337	0.9859	0.0019	1.5645
	6-month	0.0269	1.0825	0.0338	0.9564	0.0019	1.5361
	12-month	0.0268	1.0437	0.0338	0.9166	0.0017	1.5007
	18-month	0.0266	1.0291	0.0337	0.9047	0.0010	1.4768
	18-month*	0.0267	1.1288	0.0337	1.0025	0.0013	1.5831
60% S&P 500 Index and 40% WTI Crude Oil Futures	1-month	0.0285	1.2640	0.0365	1.1483	-0.0002	1.6800
	3-month	0.0288	1.1611	0.0368	1.0367	0.0000	1.6086
	6-month	0.0289	1.1133	0.0370	0.9874	0.0000	1.5660
	12-month	0.0289	1.0503	0.0370	0.9211	-0.0003	1.5146
	18-month	0.0286	1.0263	0.0369	0.9001	-0.0012	1.4800
	18-month*	0.0287	1.1791	0.0368	1.0513	-0.0007	1.6385

Table 2.8 Sharpe Ratio of WTI Crude Oil Futures Portfolios

This table shows the Sharpe ratio of each portfolio that is constructed with WTI Crude Oil futures curves and S&P 500 Index. The results are presented for full, pre-crisis and post-crisis period in column one, two and three, respectively.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

Portfolios	Maturity	Aug95-May12	Aug95-May08	Sept08-May12
100% S&P 500 Index		0.0169	0.0217	0.0047
90% S&P 500 Index and 10% WTI Crude Oil Futures	1-month	0.0197	0.0264	0.0036
	3-month	0.0199	0.0267	0.0036
	6-month	0.0200	0.0269	0.0037
	12-month	0.0200	0.0270	0.0036
	18-month	0.0200	0.0270	0.0035
	18-month*	0.0197	0.0266	0.0035
80% S&P 500 Index and 20% WTI Crude Oil Futures	1-month	0.0217	0.0300	0.0023
	3-month	0.0224	0.0311	0.0024
	6-month	0.0227	0.0317	0.0025
	12-month	0.0231	0.0323	0.0024
	18-month	0.0231	0.0324	0.0021
	18-month*	0.0221	0.0307	0.0022
70% S&P 500 Index and 30% WTI Crude Oil Futures	1-month	0.0226	0.0317	0.0011
	3-month	0.0241	0.0342	0.0012
	6-month	0.0248	0.0354	0.0012
	12-month	0.0257	0.0369	0.0011
	18-month	0.0258	0.0373	0.0007
	18-month*	0.0236	0.0336	0.0008
60% S&P 500 Index and 40% WTI Crude Oil Futures	1-month	0.0226	0.0318	-0.0001
	3-month	0.0248	0.0355	0.0000
	6-month	0.0260	0.0375	0.0000
	12-month	0.0275	0.0401	-0.0002
	18-month	0.0279	0.0410	-0.0008
	18-month*	0.0243	0.0350	-0.0005

Table 2.9 Portfolio Diversification Using Daily Returns of Copper Futures Curve

This table presents mean and volatility of each constant maturity portfolios. The return of portfolios is calculated using Equation (2.6) and the volatilities are calculated using Equation (2.7). We use the conditional covariance matrix, estimated by A-DCC model, to calculate volatility of portfolios. Each portfolio is constructed with a constant maturity Copper futures and S&P 500 Index using different weights.
*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

Portfolios	**Maturity**	**Sept95-May12**		**Sept95-Sept08**		**Sept08-May12**	
		Mean%	Vol%	Mean%	Vol%	Mean%	Vol%
100% S&P 500 Index		0.0210	1.2249	0.0241	1.1204	0.0100	1.5964
90% S&P 500 Index and 10% Copper Futures	1-month	0.0214	1.1591	0.0244	1.0491	0.0105	1.5502
	3-month	0.0214	1.1575	0.0244	1.0472	0.0106	1.5496
	6-month	0.0214	1.1544	0.0245	1.0436	0.0107	1.5485
	12-month	0.0216	1.1513	0.0247	1.0405	0.0108	1.5451
	18-month	0.0218	1.1506	0.0248	1.0401	0.0109	1.5436
	18-month*	0.0218	1.1569	0.0249	1.0466	0.0107	1.5491
80% S&P 500 Index and 20% Copper Futures	1-month	0.0217	1.1316	0.0247	1.0184	0.0110	1.5339
	3-month	0.0217	1.1250	0.0246	1.0105	0.0113	1.5322
	6-month	0.0219	1.1158	0.0248	0.9995	0.0114	1.5294
	12-month	0.0223	1.1065	0.0252	0.9896	0.0116	1.5219
	18-month	0.0225	1.1046	0.0255	0.9881	0.0118	1.5186
	18-month*	0.0225	1.1224	0.0256	1.0073	0.0115	1.5317
70% S&P 500 Index and 30% Copper Futures	1-month	0.0220	1.1414	0.0250	1.0271	0.0116	1.5476
	3-month	0.0220	1.1275	0.0249	1.0103	0.0119	1.5442
	6-month	0.0223	1.1097	0.0252	0.9888	0.0121	1.5394
	12-month	0.0229	1.0915	0.0258	0.9690	0.0125	1.5272
	18-month	0.0232	1.0878	0.0262	0.9657	0.0127	1.5218
	18-month*	0.0232	1.1210	0.0264	1.0019	0.0122	1.5442
60% S&P 500 Index and 40% Copper Futures	1-month	0.0223	1.1846	0.0252	1.0705	0.0121	1.5903
	3-month	0.0224	1.1622	0.0252	1.0434	0.0125	1.5845
	6-month	0.0227	1.1344	0.0255	1.0097	0.0128	1.5775
	12-month	0.0235	1.1054	0.0264	0.9775	0.0133	1.5602
	18-month	0.0240	1.0992	0.0269	0.9716	0.0136	1.5528
	18-month*	0.0240	1.1501	0.0271	1.0276	0.0129	1.5856

Table 2.10 Sharpe Ratio of Copper Futures Portfolios

This table shows the Sharpe ratio of each portfolio that is constructed with Copper futures curves and S&P 500 Index. The results are presented for full, pre-crisis and post-crisis period in column one, two and three, respectively.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

Portfolios	Maturity	Sept95-May12	Sept95-Sept08	Sept08-May12
100% S&P 500 Index		0.0172	0.0215	0.0063
90% S&P 500 Index and 10% Copper Futures	1-month	0.0184	0.0233	0.0068
	3-month	0.0185	0.0233	0.0069
	6-month	0.0186	0.0234	0.0069
	12-month	0.0188	0.0237	0.0070
	18-month	0.0189	0.0239	0.0071
	18-month*	0.0188	0.0238	0.0069
80% S&P 500 Index and 20% Copper Futures	1-month	0.0192	0.0242	0.0072
	3-month	0.0193	0.0244	0.0074
	6-month	0.0196	0.0248	0.0075
	12-month	0.0201	0.0255	0.0076
	18-month	0.0204	0.0258	0.0078
	18-month*	0.0200	0.0254	0.0075
70% S&P 500 Index and 30% Copper Futures	1-month	0.0193	0.0243	0.0075
	3-month	0.0195	0.0246	0.0077
	6-month	0.0201	0.0255	0.0079
	12-month	0.0210	0.0266	0.0082
	18-month	0.0214	0.0271	0.0083
	18-month*	0.0207	0.0263	0.0079
60% S&P 500 Index and 40% Copper Futures	1-month	0.0189	0.0236	0.0076
	3-month	0.0193	0.0241	0.0079
	6-month	0.0200	0.0253	0.0081
	12-month	0.0213	0.0270	0.0085
	18-month	0.0218	0.0277	0.0087
	18-month*	0.0208	0.0264	0.0081

Table 2.11 Portfolio Diversification Using Daily Returns of Soya Bean Futures Curve

This table presents mean and volatility of each constant maturity portfolios. The return of portfolios is calculated using Equation (2.6) and the volatilities are calculated using Equation (2.7). We use the conditional covariance matrix, estimated by DCC model, to calculate volatility of portfolios. Each portfolio is constructed with a constant maturity Copper futures and S&P 500 Index using different weights.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

Portfolios	Maturity	Aug95-May12		Aug95-Sept08		Sept08-May12	
		Mean%	Vol%	Mean%	Vol%	Mean %	Vol%
100% S&P 500 Index		0.0200	1.2205	0.0243	1.1170	0.0056	1.5707
90% S&P 500 Index and 10% Soya Bean Futures	1-month	0.0203	1.1275	0.0242	1.0287	0.0071	1.4618
	3-month	0.0202	1.1252	0.0242	1.0260	0.0067	1.4604
	7-month	0.0201	1.1243	0.0241	1.0247	0.0063	1.4612
	11-month	0.0199	1.1205	0.0241	1.0206	0.0055	1.4584
	11-month*	0.0202	1.1245	0.0241	1.0258	0.0068	1.4580
80% S&P 500 Index and 20% Soya Bean Futures	1-month	0.0206	1.0637	0.0241	0.9710	0.0086	1.3775
	3-month	0.0203	1.0568	0.0240	0.9633	0.0078	1.3733
	7-month	0.0201	1.0515	0.0240	0.9567	0.0071	1.3721
	11-month	0.0198	1.0397	0.0240	0.9440	0.0055	1.3633
	11-month*	0.0203	1.0546	0.0240	0.9621	0.0080	1.3676
70% S&P 500 Index and 30% Soya Bean Futures	1-month	0.0209	1.0308	0.0241	0.9452	0.0101	1.3202
	3-month	0.0205	1.0182	0.0239	0.9314	0.0090	1.3120
	7-month	0.0202	1.0052	0.0238	0.9163	0.0079	1.3058
	11-month	0.0196	0.9814	0.0238	0.8908	0.0055	1.2879
	11-month*	0.0205	1.0128	0.0238	0.9274	0.0093	1.3017
60% S&P 500 Index and 40% Soya Bean Futures	1-month	0.0212	1.0286	0.0240	0.9511	0.0116	1.2910
	3-month	0.0206	1.0100	0.0238	0.9307	0.0101	1.2782
	7-month	0.0203	0.9869	0.0237	0.9049	0.0087	1.2643
	11-month	0.0195	0.9479	0.0236	0.8631	0.0055	1.2347
	11-month*	0.0206	0.9999	0.0236	0.9224	0.0105	1.2620

Table 2.12 Sharpe Ratio of Soya Bean Futures Portfolios

This table shows the Sharpe ratio of each portfolio that is constructed with Soya Bean futures curves and S&P 500 Index. The results are presented for full, pre-crisis and post-crisis period in column one, two and three, respectively.

*Traditionally compiled (long and hold) price series which unlike rest of the price series does not have a constant maturity.

Portfolios	Maturity	Aug95-Jul12	Aug95-Sept08	Sept08-Jul12
100% S&P 500 Index		0.0164	0.0217	0.0035
90% S&P 500 Index and 10% Soya Bean Futures	1-month	0.0180	0.0235	0.0048
	3-month	0.0179	0.0235	0.0046
	7-month	0.0179	0.0236	0.0043
	11-month	0.0177	0.0236	0.0038
	11-month*	0.0179	0.0235	0.0047
80% S&P 500 Index and 20% Soya Bean Futures	1-month	0.0194	0.0249	0.0062
	3-month	0.0192	0.0249	0.0057
	7-month	0.0191	0.0251	0.0052
	11-month	0.0190	0.0254	0.0040
	11-month*	0.0193	0.0249	0.0059
70% S&P 500 Index and 30% Soya Bean Futures	1-month	0.0203	0.0255	0.0077
	3-month	0.0201	0.0257	0.0068
	7-month	0.0201	0.0260	0.0060
	11-month	0.0200	0.0267	0.0043
	11-month*	0.0202	0.0257	0.0071
60% S&P 500 Index and 40% Soya Bean Futures	1-month	0.0206	0.0252	0.0090
	3-month	0.0204	0.0255	0.0079
	7-month	0.0205	0.0262	0.0068
	11-month	0.0206	0.0274	0.0044
	11-month*	0.0206	0.0256	0.0083

Figure 2.1 Conditional correlations between WTI Crude Oil futures curves and S&P 500 Index

This figure depicts time-varying conditional correlations between daily returns of the five constant-maturity and one traditionally compiled WTI Crude Oil futures and S&P 500 Index estimated using equation (2.5). The dynamic conditional correlations are estimated by $P_t = Q_t^{*-1} Q_t Q_t^{*-1}$ where $Q_t^* = [q_{iit}^*] = \lfloor \sqrt{q_{iit}} \rfloor$ is a diagonal matrix with the square root of the ith diagonal element of Q_t on its ith diagonal position and P_t is a correlation matrix with ones on the diagonal and every other element ≤ 1 in absolute value.

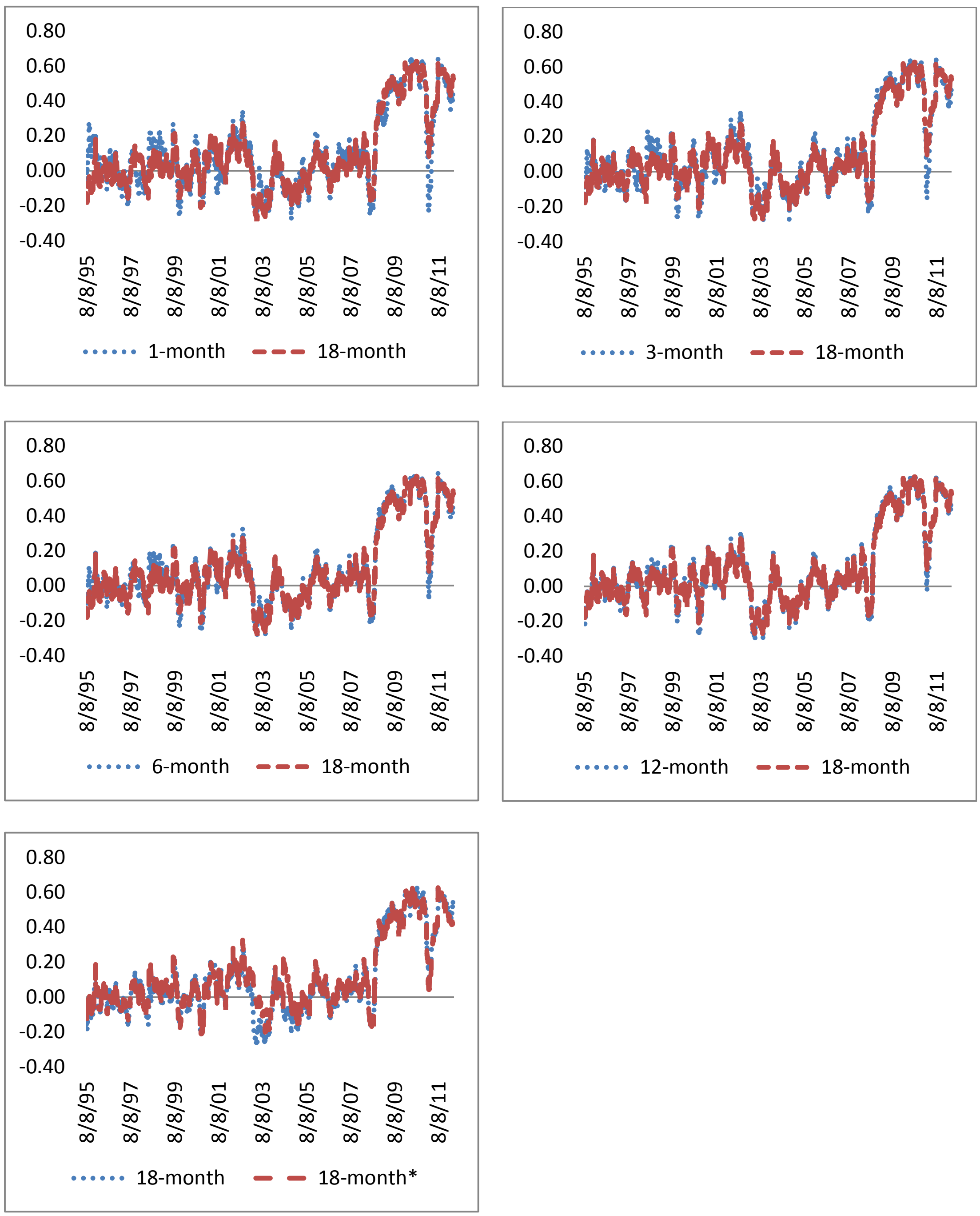


Figure 2.2 Conditional correlations between Copper futures curves and S&P 500 Index

This figure depicts time-varying conditional correlations between daily returns of the five constant-maturity and one traditionally compiled Copper futures and S&P 500 Index estimated using Equation (2.5). The dynamic conditional correlations are estimated by $P_t = Q_t^{*-1} Q_t Q_t^{*-1}$ where $Q_t^* = [q_{iit}^*] = \lfloor \sqrt{q_{iit}} \rfloor$ is a diagonal matrix with the square root of the ith diagonal element of Q_t on its ith diagonal position and P_t is a correlation matrix with ones on the diagonal and every other element ≤ 1 in absolute value.

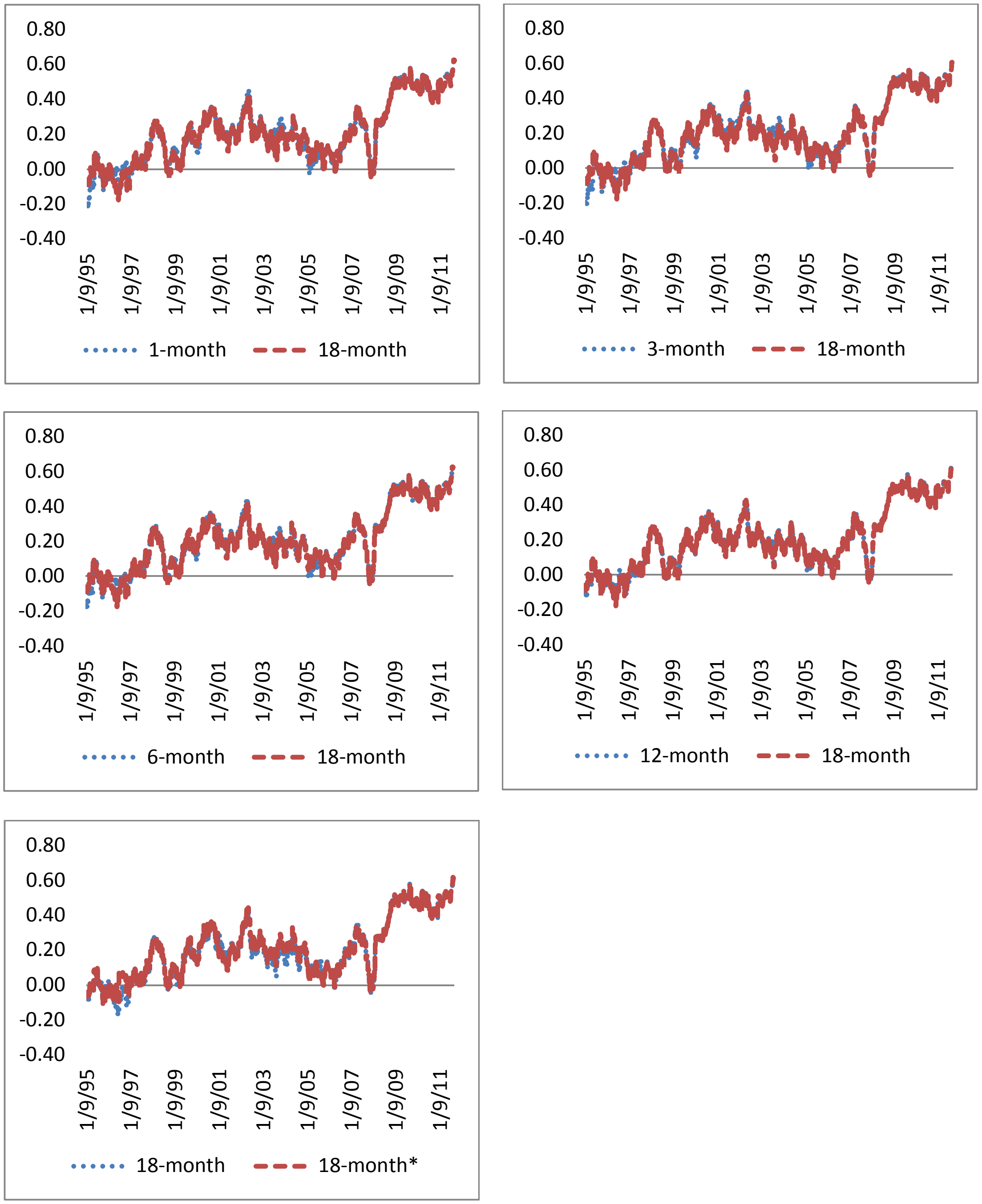


Figure 2.3 Conditional correlations between Soya bean futures curves and S&P 500 Index

This figure depicts time-varying conditional correlations between daily returns of the four constant-maturity and one traditionally compiled Soya Bean futures and S&P 500 Index estimated using Equation (2.3). The dynamic conditional correlations are estimated by $P_t = Q_t^{*-1} Q_t Q_t^{*-1}$ where $Q_t^* = [q_{iit}^*] = \lfloor\sqrt{q_{iit}}\rfloor$ is a diagonal matrix with the square root of the ith diagonal element of Q_t on its ith diagonal position and P_t is a correlation matrix with ones on the diagonal and every other element ≤ 1 in absolute value.

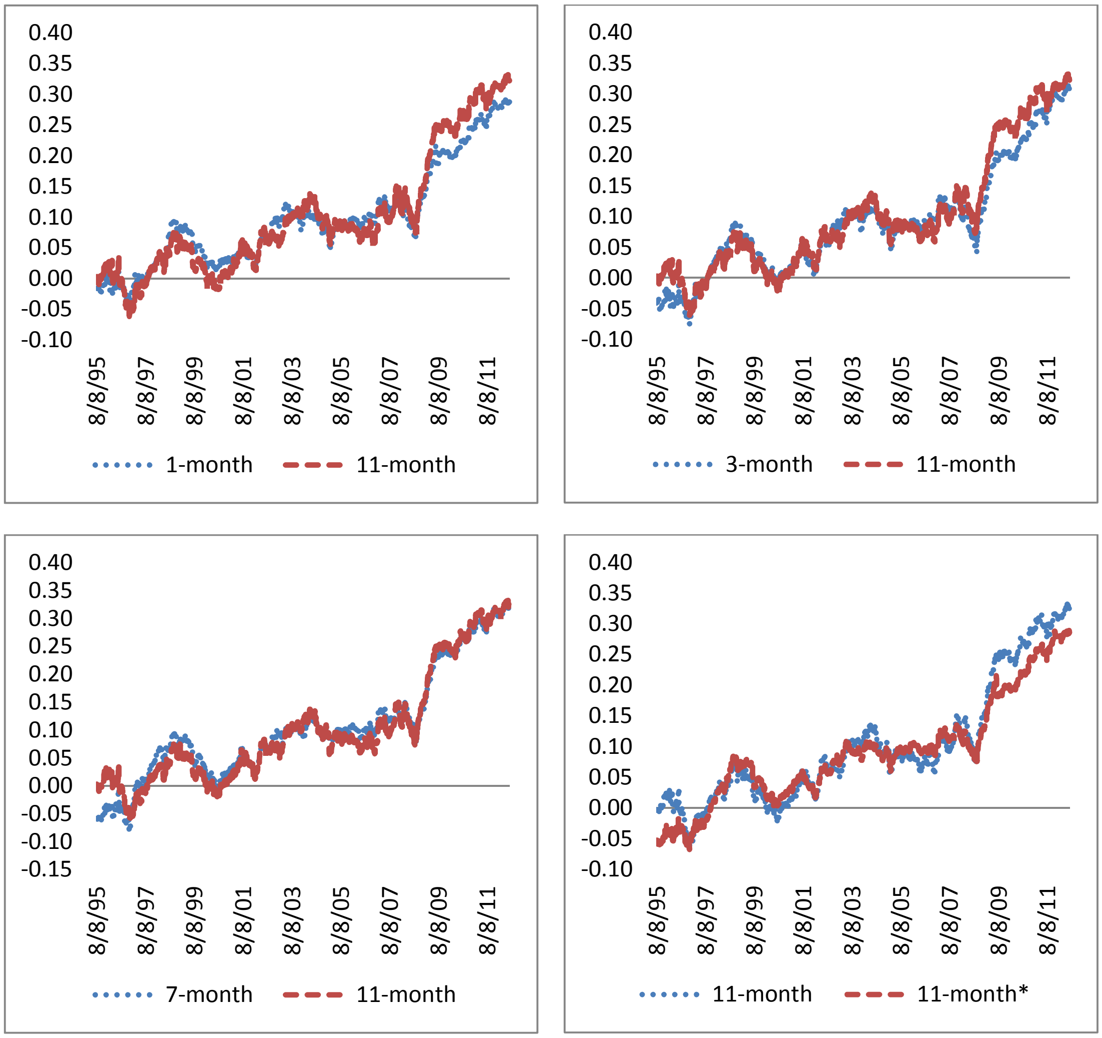
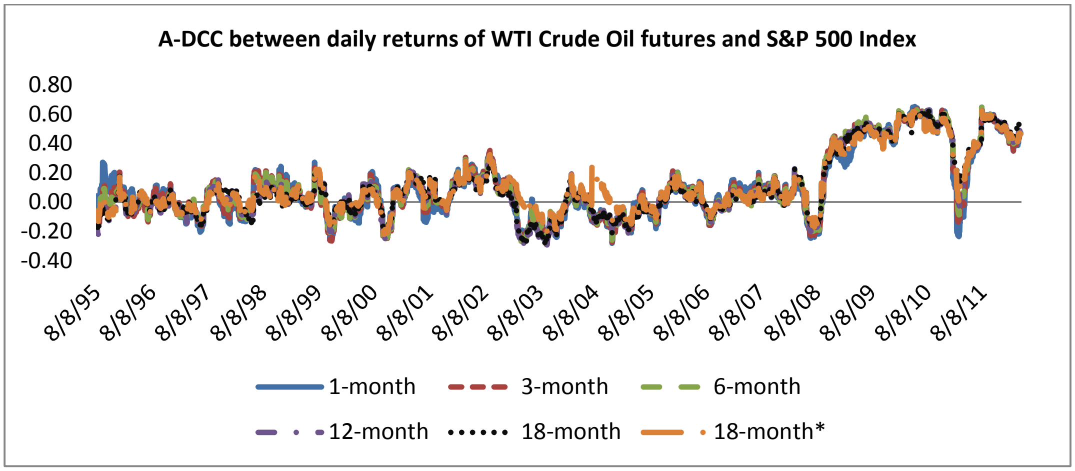
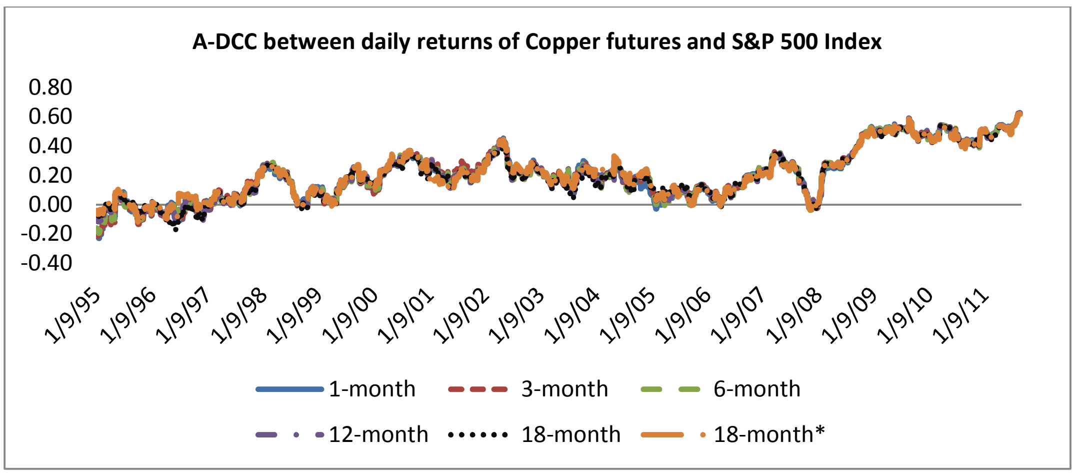
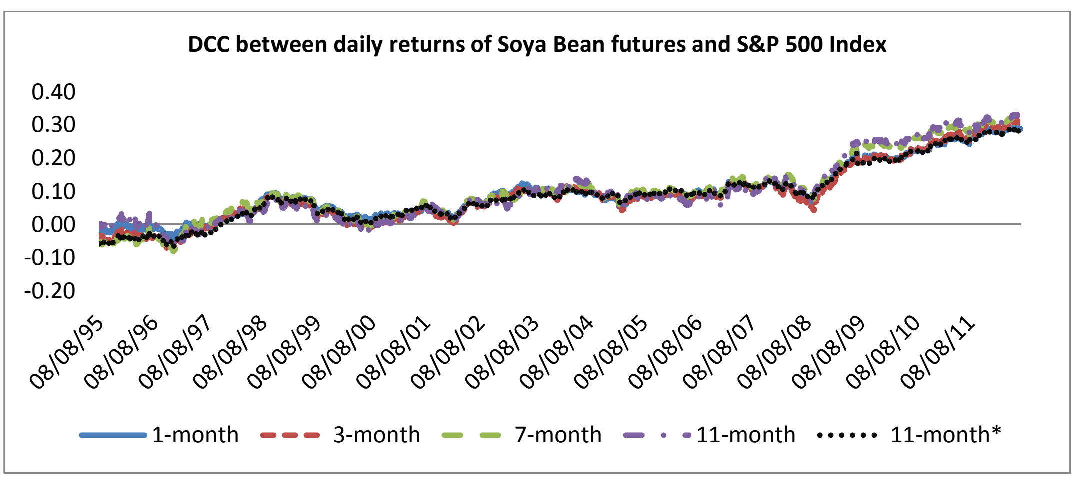


Figure 2.4 Conditional Correlations All Maturities

This figure shows time-varying conditional correlations between each commodity futures curves and S&P 500 Index for all commodities.







Appendix

Table 2.13 Univariate GARCH (1, 1) Parameter Estimations

This table shows the Univariate GARCH parameter estimations that are used to standardize return series of each commodity futures and S&P 500 Index. A simple GARCH (1, 1) model ($h_t = \omega + \alpha\varepsilon_{t-1}^2 + \beta h_{t-1}$) is selected for parameter estimations according to AIC criterion. The numbers underlined are t-statistics.

	ω	α	β
S&P 500 Index	0.0000	0.0854	0.9058
	3.10	*7.96*	*86.30*
Panel (a) WTI Crude Oil Futures			
1-month maturity	0.0000	0.0516	0.9314
	1.75	*2.97*	*36.88*
3-month maturity	0.0000	0.0429	0.9442
	2.12	*3.48*	*56.07*
6-month maturity	0.0000	0.0499	0.9317
	1.41	*2.26*	*28.33*
12-month maturity	0.0000	0.0487	0.9412
	2.24	*4.23*	*65.61*
18-month maturity	0.0000	0.0519	0.9380
	2.36	*4.39*	*64.78*
Panel (b) Copper Futures			
1-month maturity	0.0000	0.0523	0.9357
	2.76	*4.99*	*68.85*
3-month maturity	0.0000	0.0397	0.9521
	2.07	*4.61*	*79.39*
6-month maturity	0.0000	0.0384	0.9545
	2.51	*4.35*	*85.31*
12-month maturity	0.0000	0.0393	0.9544
	2.09	*3.89*	*74.38*
18-month maturity	*0.0000*	*0.0429*	*0.9513*
	1.99	*3.94*	*70.25*
Panel (c) Soya Bean Futures			
1-month maturity	0.0000	0.0868	0.9010
	2.37	*3.50*	*37.16*
3-month maturity	0.0000	0.0582	0.9285
	2.55	*3.44*	*49.57*
7-month maturity	0.0000	0.0602	0.9212
	3.31	*4.50*	*56.65*
11-month maturity	0.0000	0.0564	0.9289
	3.24	*6.15*	*78.37*

Table 2.14 (A)-DCC Parameter Estimations

This table presents parameter estimations for dynamic conditional correlations between logarithmic returns of each commodity futures and S&P 500 Index. We use A-DCC model for WTI and Copper, and DCC model for Soya Bean futures. The equations are given in Equation (2.3) and (2.5) for DCC and A-DCC models respectively. We chose an (A)DCC-MVGARCH (1, 1, 1) model according to AIC criterion. The numbers underlined are t-statistics.

	a	g	b
Panel (a) WTI Crude Oil Futures			
1-month maturity-S&P 500 Index	0.0169	0.0080	0.9778
	4.05	1.78	177.57
3-month maturity-S&P 500 Index	0.0160	0.0081	0.9785
	3.26	1.76	140.26
6-month maturity-S&P 500 Index	0.0150	0.0077	0.9798
	2.97	2.33	165.94
12-month maturity-S&P 500 Index	0.0148	0.0075	0.9802
	4.38	1.57	210.93
18-month maturity-S&P 500 Index	0.0134	0.0060	0.9826
	3.56	2.72	133.64
Panel (b) Copper Futures			
1-month maturity-S&P 500 Index	0.0096	0.0042	0.9878
	3.55	1.91	250.56
3-month maturity-S&P 500 Index	0.0096	0.0039	0.9879
	2.25	1.95	159.32
6-month maturity-S&P 500 Index	0.01	0.0039	0.9875
	2.35	2.16	188.40
12-month maturity-S&P 500 Index	0.0097	0.0036	0.988
	0.31	1.89	17.27
18-month maturity-S&P 500 Index	0.0099	0.0038	0.9877
	2.89	1.65	238.24
Panel (c) Soya Bean Futures			
1-month maturity-S&P 500 Index	0.0021	-	0.9979
	1.07	-	375.60
3-month maturity-S&P 500 Index	0.0024	-	0.9975
	2.38	-	585.69
7-month maturity-S&P 500 Index	0.0023	-	0.9976
	2.28	-	721.74
11-month maturity-S&P 500 Index	0.0026	-	0.9973
	2.56	-	159.09

Chapter 3

Determinants of Volatility along Commodity Futures Curves: Effects of Inventory, Trading Volume, Open Interest and Speculators

3.1 Introduction

Over the last decade there have been significant changes in commodity markets. For example, there was a dramatic increase in commodity prices during the first decade of the 2000s; crude oil prices rose almost 500% from 2002 to mid-2008 accompanied by high volatility which sometimes varied almost 80% in a single year. Moreover, there has been significant growth in the funds invested in commodity futures markets totalling to above $200 billion by mid-2008 from $15 billion in 2003, CFTC (Commodity Futures Trading Commission).

Speculators have been accused causing or exacerbating the sharp price increases and high volatility in commodity markets especially after the testimony of hedge fund manager Michael W. Masters before the US Congress and the US CFTC, which is now known as the Masters Hypothesis (Masters, 2008, 2009). On this matter understanding the rationale for changes in commodity price movements, especially price volatility, is crucial for market players from hedgers to futures contracts traders. For example, the optimal margins on futures contracts trading are set by futures contracts price volatility and have a positive relationship; an increase in price volatility leads to an increase in margin requirements Hardouvelis and Kim (1996). Hedging ratios are adjusted based on volatility of futures contracts. Moreover, speculators take positions in futures contracts according to their expectation of futures price variability as greater volatility brings more profits. Further, futures contracts volatility is an input for option pricing. The aim of this chapter is to analyse the price volatility of WTI Crude Oil futures contracts from a futures curves perspective as there are contracts with different maturities traded in the market and used by market participants.

Samuelson (1965) argued that the volatility of futures prices increases when a contract approaches to maturity, is the so-called maturity effect, and this has been heavily investigated in the literature (such as Duong and Kalev (2008), Bessembinder et al. (1996) and Ripple and Moosa (2009)). The results to date are mixed, although it is argued that the hypothesis is most supported in agricultural markets (Duong and Kalev, 2008). The theory of storage from Kaldor (1939) and Working (1948, 1949) suggests that inventory and volatility of spot prices have a negative relationship, and that the volatility of spot prices is higher than the volatility of futures prices during times of scarcity, which is also heavily investigated in the literature. For example, Geman and Smith (2013) found that volatility of spot prices is higher than volatility of 3-month maturity futures prices when the inventory is less than 10 days in the LME metals market. Routledge et al. (2000) found that conditional violations to the Samuelson hypothesis occur in their equilibrium term structure model at short horizons when inventory is sufficiently high, the forward price volatility increases with contract horizon. Other studies also found negative relationship between inventory and volatility, such as Symeonidis et al. (2012), Geman and Nguyen (2005) and Geman and Ohana (2009).

Furthermore, recent empirical analysis (such as Irwin and Sanders (2012), Sanders and Irwin (2011), and Buyuksahin and Harris (2011)) has also investigated the argument that ‘financialisation’ and increased speculation distorts commodity futures prices, the so-called Masters Hypothesis. However, these studies fail to find any evidence that speculators destabilize financial markets. Other studies analysed if speculator activities affect the volatility of futures prices. For example, Manera et al. (2014) found that speculation has a negative effect on futures price volatility in all four energy commodities that they analysed. On the other hand, Aulerich et al. (2013) found that Commodity Index Trader (CIT) positions do not affect the 12 agricultural commodities that they studied.

In this chapter, we investigate the impact of inventory, trading volume, open interest and market share of speculators on volatility of WTI crude oil futures with five constant maturities; 1-month, 3-month, 6-month, 12-month and 18-month. This study is the first to use constant maturity futures contracts and analyse volatility comprehensively using both fundamentals and speculators variables to the best of my knowledge. Moreover, we examine the effect of 2008 financial crisis on the determinants of volatility using pre and post-crisis subsamples. We analyse how the relationship between explanatory variables and volatility changed before and after that period.

First of all, our analyses confirms that open interest presents a negative relationship with volatility while trading volume has a positive one in all the maturities we studied. The inventory variable also gives some interesting results. It is found that inventory and up to 6-month maturity futures volatility has a negative relationship, while this is reversed for 12 and 18-month maturity, and in fact inventory in 18-month maturity is as high and significant as in 1-month maturity with an opposite sign. This result indicates that high (low) inventory decreases (increases) volatility in near maturity futures while it increases (decreases) volatility in long-maturity futures. This might be explained with the expectation of market participants; because inventory is mean reverting in nature, a high supply now means that traders might expect a low supply in the future and this affects long-maturity futures prices in the opposite manner.

Moreover, the market share of speculators also gives some interesting results. Its estimated coefficient in volatility models is found to be negative and significant for 1-month maturity, becoming positively signed with maturity although not significant. Hence, one might think that speculators' positions do not affect long-maturity futures in our full sample. However, the results from pre and post-crisis subsamples are quite intriguing. It is revealed that speculators and volatility has a negative and significant relationship in all maturities in pre-crisis period; while it is found to be positive and significant in all maturities in the post-crisis period, except for the 1-month maturity where it is also positive but not significant. Hence, our results indicate that speculators have exacerbated market volatility in the post-crisis period. This is in fact in contrast to the findings of Manera et al. (2014) from short-maturity futures volatility perspective. They found that speculators variable is negative in WTI crude oil futures market and concluded that they do not distort market prices. Although their data period also covers the 2008 financial crisis they do not analyse subsample periods.

Finally, to get a better understanding of the relationship between volatility and inventory, and volatility and speculators variables we use rolling and recursive regressions. The results confirm our findings that inventory and long-maturity futures price volatility has a positive relationship which peaks up especially after 2008 financial crisis period; while inventory and short-maturity futures price volatility has a negative relationship. Moreover, the significant positive relationship between 18-month maturity futures price volatility and market share of speculators is also confirmed using same technique. These findings inform market participants. For example, if a trader invests in a long maturity futures contract and the inventory in that market is currently high, then he/she should expect that the volatility might be higher than he/she anticipated (as high inventory will increase the volatility) and hence should adjust cash balances. Last but not least, it is found that these explanatory variables also have in-sample forecasting ability for the volatility of futures prices of all maturities studied.

The remainder of the chapter is organized as follows. The next section presents the literature on determinants of commodity futures price volatility. Section 3.3 describes the data construction and the methodology used in volatility analysis. In Section 3.4 empirical findings are given and last section concludes this chapter.

3.2 Literature

The volatility in the commodity futures market has been heavily investigated in the literature; both in terms of spot price[1] volatility and the term structure of volatility. In terms of the volatility in the commodity futures markets there are two main hypothesis; the Samuelson (1965) hypothesis, the so called maturity effect, and the theory of Storage by Kaldor (1939) and Working (1948, 1949). Samuelson (1965) showed that the volatility of futures prices should increase as the contract approaches to its maturity. There are many studies that examined this hypothesis in numerous commodity futures markets, such as; Duong and Kalev (2008), Ripple and Moosa (2009), Bessembinder et al. (1996), and Grammatikos and Saunders (1986), however the results are mixed. For example, Duong and Kalev (2008) found supporting evidence in agricultural markets but none in the other three markets that they were studying (metals, energy and financial futures). Moreover, Grammatikos and Saunders (1986) fail to find supporting evidence of hypothesis in five financial futures markets, while Barnhill et al. (1987) found some support for the evidence

[1] Most of the studies use near-month futures prices as a proxy for spot price because of the convenience and easily availability of the data.

in the US Treasury Bond Futures. Some of these studies analysed the impact of trading volume and open interest in addition to maturity in futures price volatility. Ripple and Moosa (2009) found that trading volume and open interest have significant roles in determining the futures price volatility and that dominates the maturity effect in the crude oil market that they studied. They use both contract-by-contract analysis and time series analysis that covers the period from 1995 to 2005. They also argue that the positive maturity effect on volatility might be the influence of open interest, where open interest has negative effect on volatility and it becomes smaller with maturity.

The theory of storage of Kaldor (1939) and Woking (1948, 1949) introduce the term of “convenience yield” which is the utility that earned by holders of inventories especially during scarce supply conditions. The theory of storage also predicts that the volatility of futures prices and inventory has a negative relationship. Many studies in the literature studied both the relationship between inventory and forward curves, and volatility. For example, Symeonidis et al. (2012) analysed the relationship between volatility and inventory in 21 commodity markets with real inventory data and found that there exist a negative relationship. They used nearby futures volatility, 2-month basis and 6-month basis volatility for the period 1993-2011, and found that the relationship is stronger between nearby futures volatility and inventory than between basis volatility and inventory. Geman and Nguyen (2005) also found that spot price volatility in soybean futures market is a monotonically increasing function of scarcity, which is a term for inverse of the inventory. Geman and Ohana (2009) also find that crude oil inventory is negatively correlated to volatility of front-month futures regardless of the scarcity, however in natural gas market the negative correlation prevails only in periods of scarcity where stocks are below their historical average. They also argue that geopolitical factors play an important role in explaining the long-term price volatility as the correlation between crude oil inventory and volatility increases when they use US inventory instead of OECD petroleum products inventory. Moreover, Geman and Smith (2013) studied the theory of storage in LME base metals market and found that there exist a negative relationship between inventory and spot price volatility. They also introduced excess volatility concept, which is a ratio of the difference between volatility of spot prices and 3-month maturity futures prices over 3-month futures prices. They found that volatility of spot price is never less than volatility of 3-month futures prices supporting Samuelson hypothesis. However, they also found that there are times when spot price volatility does not exceed futures price volatility although the inventory is low. Furthermore, they argue that in the condition of scarcity spot prices and the spot price volatility will increase, however the volatility of the long-term futures will be affected very little as its prices mainly respond to longer term news.

The term structure of volatility in commodity futures market has been also studied with a stochastic volatility approach, in which unobserved factors determine asset return volatility. For example, Geman and Nguyen (2005) found that adding scarcity, inverse of inventory, as a third state variable into the stochastic component of spot price and its short term mean considerably improves the quality of the estimation of the forward prices in soybean futures market. Chiarella et al. (2013) found a hump-shaped, partially spanned stochastic volatility in the crude oil market with a multi factor stochastic volatility model. Moreover, Karali et al. (2010) studied the difference in the volatility dynamics of corn, soybeans and oat futures prices. They found that the inventory effect for corn varies across delivery horizons having the highest magnitude in the second-nearby contract, while there is not much difference across soybean contracts. Moreover, they found that the volatility differs in all three commodities in the production cycle (planting, pre-harvest and post-harvest).

Furthermore, the effect of speculation in commodity futures prices has been heavily investigated. For example, Singleton (2014) argue that even after controlling for many of the conditioning variables that effect price behaviour in oil futures markets, investor flows also affects futures prices economically and significantly. They found that growth in positions of index investors and managed-money accounts have significant positive effect on returns in oil futures markets around the 2008 boom/bust in addition to stock returns in US and emerging economies, open interest and lagged futures. Manera et al. (2014) investigated the effect of speculation in energy futures market volatility. By using the market share of non-commercial traders, the Working's T Index and the percentage of net long positions of non-commercials over total open interest as a measures of speculation they found that it has a negative and significant effect on four energy futures market; crude oil, heating oil, gasoline and natural gas. They argue that their results indicate speculation does not destabilize futures prices.

3.3 Data and Volatility Analysis

3.3.1 Data

We collect data of daily futures prices of WTI Crude Oil from DataStream[2]. Weekly Tuesday[3] settlement futures prices of all individual contracts that are traded on that day are used for the period October 1992- April 2012 to construct our weekly frequency price series. We also have two sub-sample periods; pre-crisis period covering data from October 1992 to September 2008, and post-crisis period covering data from September 2008 to April 2012. Number of observations for full period is 1036, pre-crisis is 830 and post crisis is 206. Constant maturity time series with 1-month, 3-month, 6-month, 12-month and 18-

[2] WTI Futures Contracts traded on New York Mercantile Exchange.
[3] We choose Tuesday to avoid price anomalies related to beginning and end of the week.

month maturity are constructed from these individual contracts.[4] Constant maturity time series are constructed as explained in second chapter of this research. Moreover, daily High and Low prices of individual futures contracts for the same period also obtained from DataStream and same methodology used to construct constant maturity price series to calculate high-low volatility at a weekly frequency. Open interest and trading volume of corresponding maturities are also obtained from DataStream for the same time period. For example, the open interest used in the analysis of 1-month maturity futures volatility also has constant 1-month maturity. The effect of inventory on commodity price volatility has been heavily analysed in the literature since the theory of storage of Working (1948). Hence, we collect weekly US Ending Stocks of Crude Oil and Petroleum products from the reports provided by EIA (Energy Information Administration). Moreover, US Commodity Futures Trading Commission (CFTC) publicly reports data on positions of hedgers and speculators at weekly frequency. We collect weekly prices of these two groups of traders to build measures of speculative activity that we use in our analysis. We use two types of speculation indices; Working T index and market share of non-commercial traders.

Market share of non-commercial traders, proposed by Buyuksahin and Robe (2014), the average of speculator positions to all open interest in that market computed as;

$$\frac{SL + SS}{2 * OI} \tag{3.1}$$

where SL is number of long positions and SS is the number of short positions held by speculators while OI is the total open interest in that market. In these CFTC reports also position of Non-Reportable traders are published. We follow Manera et al. (2014) and treat

[4] Constant maturity is obtained by rolling the contracts over on the last trading day of every month.

them as 50% of speculators and 50% of hedgers, as they found that treating those positions as all speculators or with different percentages does not affect the results.

Moreover, other measure of speculation activity, Working T index, defined by Sanders et al. (2008), as follows;

$$T = 1 + \frac{SS}{HS + HL} \; if \; HS \geq HL, \qquad (3.2)$$
$$T = 1 + \frac{SL}{HS + HL} \; if \; HS \leq HL$$

Here SS and SL as above, HS is the short position of speculators and HL is the long position. This index measures the excessive speculative positions beyond what is needed to balance commercial traders' needs. The non-reportable positions are treated as in market share of speculators.

3.3.2 Volatility Analysis

We estimate the weekly volatility of five constant maturity futures, which are constructed from daily prices of individual trading contracts, using a GARCH (1, 1) model;

$$r_t = \mu + \varepsilon_t \text{ where } \varepsilon_t = \sigma_t z_t \text{ and} \qquad (3.3)$$

$$\sigma_t^2 = \omega + \alpha\varepsilon_{t-1}^2 + \beta\sigma_{t-1}^2 \qquad (3.4)$$

where we use logarithmic returns. The volatility series obtained by GARCH (1, 1) model is given in graph (a) in Figure 3.1. We check all of our variables for the presence of unit root. We found that all our explanatory variables; inventory, trading volume, open interest, market share of speculators and Working T index are trend stationary. Hence, we de-trend all our variables by running regression on each series against a constant and linear time trend, and collecting the residuals to use in our analysis. Figure 3.2 illustrates the time series of Market Share of Speculators and Working T Index with both original and detrended series.

We use the model below to analyse the impact of our explanatory variables on volatility of different maturity price series at weekly frequency[5];

$$\sigma_{i,t} = \alpha + \beta tv_{i,t} + \gamma oi_{i,t} + \theta inv_{t-1} + \delta spec_t + \varepsilon_t \qquad (3.5)$$

Here $\sigma_{i,t}$ is the conditional volatility that estimated using GARCH (1, 1) model and $i = 1, 3, 6, 12 \; and \; 18$ represents the maturity of the futures contracts. $tv_{i,t}$ is the de-trended trading volume and $oi_{i,t}$ is the de-trended open interest of the futures contracts specific to their maturities, inv_{t-1} is the de-trended and lagged US Ending Stocks of Crude Oil and Petroleum products, inventory data. $spec_t$ is the market share of non-commercial (speculators) trader positions which is calculated using Equation (3.1) above. The regressions are run with each individual variable and with different combinations of explanatory variables to be able to see the effect of each individual variable on different constant maturity volatilities. The analyses are carried out for the full sample period as well as pre and post-crisis periods. The estimation in our analysis employs a least-squares methodology and the covariance matrix of coefficients is obtained by Newey and West (1987) estimator to avoid heteroscedasticity and autocorrelation issues.

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[5] As a robustness check, we rerun our regressions using Working T index calculated using Equation (4.2) as a speculation variable instead of market share of speculators and the results are similar.

Moving on, we analyse the forecasting ability of the explanatory variables on constant maturity volatilities using equation below;

$$\sigma_{i,t} = \alpha + \sigma_{i,t-1} + \beta tv_{i,t-1} + \gamma oi_{i,t-1} + \theta inv_{t-1} + \delta spec_{t-1} + \varepsilon_t \qquad (3.6)$$

Here, all the explanatory variables are lagged once and also we add lag of volatility into the equation to be able to observe the explanatory power of other variables. Furthermore, as the results from our analyses were not straightforward, especially the effect of inventory and market share of speculators on the volatility of different maturities, we use rolling and recursive regression methodology to get a better understanding of the effect of these two explanatory variables on the volatility. We use a two years calibration period, 104 observations, in our analysis. These analyses are only done for 1-month and 18-month maturity volatility as the variables were behaving differently especially at these horizons.

Last but not least, we use Parkinson's (1980) High-Low volatility estimator, one of the first and widely accepted methods of estimating volatility, to compare the results obtained in our analysis using GARCH estimated volatility. He argues that the diffusion constant of the underlying random walk of the stock price movements is the true variance of the return of a stock over a unit of time. Hence, he recommends that this extreme value method should be used to estimate the variance of the return of stocks. The High-Low volatility estimator σ_{hl} for the weekly frequency over a 12 weeks calibration period can be calculated using;

$$\sigma_{hl}{}^2 = \frac{1}{4 * \ln(2) * n} * \sum_{i=1}^{n} \frac{H_i{}^2}{L_i} \qquad (3.7)$$

Where n is the calibration period, 12 weeks in our analysis, H_i and L_i are the High and Low futures prices of the week, and $\frac{1}{4*\ln(2)}$ is the factor to ensure that observed set $\frac{H_i}{L_i}$ originates from a random walk. The graph (in b) Figure 3.2 presents the volatility series that are calculated by high-low volatility estimator. The results are in fact similar.

3.4 Empirical Findings

First of all, Figure 3.1 indicates that the weekly volatility of 1-month maturity futures is the highest among all maturities and the volatility declines with maturity (i.e, the 18-month maturity volatility being the lowest). In fact, this is in favour of Samuelson (1965) hypothesis; he argues that volatility of futures contracts increases with time to maturity. Our goal is to analyse the determinants of volatility of these five different maturity futures series; in other words, how other variables affect the volatility apart from the maturity. In fact, the results are quite striking.

Panel (a) of Table 3.1 shows the results for 1-month maturity volatility for full sample period, while panel b and panel c indicates results from pre and post-crisis period. Coefficient of inventory and open interest are negative and significant; while trading volume is positive and significant as expected. However, it seems that open interest and trading volume are not significant when used as only explanatory variable in the equation, column (2) and (3) respectively; while inventory is quite significant in column (1). Moreover, market share of speculators is negative and quite significant, which is in favour of findings of Manera et al. (2014). Results in Panel (b) pre-crisis period, are similar in terms of the signs of the variables. However, it seems that the inventory and speculators variables are more significant and have greater impact on volatility in pre-crisis period than trading volume and open interest as later ones lose their significance in full equation, column (10). Results in post-crisis period, given in Panel (c), are interesting as the speculator variable becomes positive although not significant. This is not surprising given the fact that there is a jump in the market share of speculators just before 2008 financial crisis as shown in Figure 3.2.

Table 3.2 gives the results of 3-month maturity volatility. The signs of variables are as expected in full period. Moreover, it seems that speculators variable dominates inventory as it can be seen in column (7), (8) and (9). Results in pre-crisis period is also as expected and similar to those in 1-month maturity, inventory and speculators are significant and negative, while open interest and trading volume lose their significance in full equation, column (10). Finally, post-crisis period results are interesting in terms of speculator variable where it is positive and significant while it was positive but not significant in 1-month maturity. Results in Table 3.3, 6-month maturity volatility are similar to that 3-month maturity. Speculators and inventory are both negative but not significant while open interest and trading volume has the correct sign and significant in full period. What is interesting is that inventory is not significant when it is used as only explanatory variable although it was in 1 and 3-month maturity. Moreover, speculators variable is positive and significant as well in post-crisis period as it was in 3-month maturity.

Table 3.4 depicts the results for the 12-month maturity volatility and gives some interesting outcomes. First of all, the estimated coefficients for trading volume, open interest and the speculation variables are similar to those in other maturities in full period. Exceptions include that inventory is positive although not significant in full period. In both pre and post-crisis period all the variables have similar signs and significance in comparison to other maturities. However, inventory and open interest seems to be dominated by trading volume and speculators variables in the pre-crisis period in comparison to other maturities.

Last but not least, Table 3.5 gives results for the 18-month maturity volatility. Open interest is as expected whilst trading volume and speculation are negative but not significant, but most interestingly, inventory is positive and significant over the full period. Note also that inventory and open interest seem to dominate trading volume and speculation in the full period column (10) results. In the post-crisis period speculation variable is positive and significant as it was in all maturities apart from 1-month one, and open interest and trading volume present the opposite sign and significant.

Given the estimated coefficient for the inventory variable is significant and positive in 18-month maturity case (in contrast to 1-month maturity) over the full sample period but not in either sub-sample, interpretation of the results is not quite so straightforward. Furthermore, speculation being positive in the post-crisis period and significant for all maturities but 1-month is also puzzling. To investigate further, we use both rolling and recursive regressions between 1-month maturity volatility and inventory/speculation, and 18-month maturity volatility and inventory/speculation variables with a two year calibration period to be able to analyse the variation in these estimated coefficients over time. Results are given in Figure 3.3 and 3.4 for inventory, and in Figure 3.5 and 3.6 for speculators. The t-statistics from the rolling regression in Figure 3.3 show that, although having a similar pattern in both maturities, the periods when the estimated coefficient of inventory is positive in 18-month maturity is always significant (especially in post-crisis period) while this not the case in 1-month maturity. Moreover, recursive regression in Figure 3.4 support the results from rolling regression as a clear positive pattern emerges in 18-month maturity just before the 2008-financial crisis and it is significant while it is not true for 1-month maturity. Results from speculation are also interesting. The rolling regression in Figure 3.5 confirm that during the post-crisis period, the increase in market share of speculators in fact increased volatility in crude oil markets, given the positive and significant values of the estimated coefficients for the 18-month contract. Importantly, for the 1-month maturity, this effect is far less obvious. The recursive regression results in Figure 3.6 also suggest that the sign of the coefficients on the speculation variable become more positive for both maturities considered for the post-2008 period. However, the lack of significance in these latter recursive approaches shows the relevance of using a rolling methodology and more effectively splitting the sample into separate time periods.

As a robustness check we run the same analysis for all constant maturity series using a different volatility and speculative activities variable. Our volatility variable is estimated using Parkinson (1980) High-Low volatility estimator and speculative activities variable is Working T index as given in equation (3.2). The results for 1-month, 3-month, 6-month, 12-month and 12-month maturities are given in Table 3.6, 3.7, 3.8, 3.9 and 3.10, respectively. It can be seen that the results are similar to the one obtained using volatility series obtained from GARCH model and Market Share of Speculators variable. It can be seen from the results that the striking finding of having a positive relationship between inventory variable and 18-month maturity volatility is present. Moreover, the speculative variable, Working T Index, also have the similar results that obtained using market share of speculators; has a negative relationship in pre-crisis period which reverses in post-crisis period.

Last but not least, Table 3.11 to 3.15 shows the results from equation (3.6) where we analyse the in-sample forecasting ability of these explanatory variables. Results are similar to those in main equation, inventory is negative up to 6 month maturity while it is positive for 12 and 18-month maturity, open interest and trading volume and expected signs and are significant, speculators variable is negative in pre-crisis and positive in post-crisis period in all maturities. It indicates that in fact these variables have forecasting ability for all maturities used. However, once the lagged volatility taken into account other variables lose their significance. But still, some of the variables survive the dominance of lagged volatility; inventory, open interest and speculators in 1-month maturity; inventory, trading volume and speculators in 3-month maturity; only inventory in 6-month maturity; none in 12-month and only trading volume in 18-month maturity.

3.5 Conclusion

It is suggested in the literature from both theoretical and empirical perspective that volatility and inventory have a negative relationship (see Working ,1949, Geman and Smith ,2013 and Symeonidis et al. ,2012); that trading volume has a positive and open interest has a negative effect on volatility (see Ripple and Moosa, 2009). It is also argued, first by Samuelson (1965), that commodity futures become more volatile with maturity. Moreover, it has been recently argued that, especially after the 2008 financial crisis, that speculator activities distort market prices, increase trading volume, and hence increase volatility (see Manera et al., 2014). However, empirical findings on all these issues are mixed and typically, those studies analyse the volatility by using spot prices or nearby futures contracts, ignoring the rest of the term structure. In this study, we analyse comprehensively the effect of inventory, trading volume, open interest and market share of speculators on the volatility of commodity futures contracts with different constant maturities.

Overall, our results indicate that the theorized negative impact of open interest and positive effect of trading volume on volatility is confirmed from a commodity futures curves perspective. However, new results include that inventory affects longer-term (i.e., including 18-month maturity) futures volatility. Moreover, this relationship is positively signed, unlike the conventional shorter maturity volatility, which is negatively signed. This in fact in contrast to the argument of Geman and Smith (2013) as they mentioned that inventory affects long-maturity futures little as its prices mainly respond to longer term news. The positive effect of inventory on longer maturity futures price volatility might be explained by expectations of market participants and mean reverting nature of inventory. A high supply now means that market participants expect scarcity in the future which distorts long-maturity futures prices and hence leads to higher volatility in longer maturities.

Other striking results include those related to speculation. We found that it has a significant and negative effect on volatility in the pre-crisis period but this switches to a positive and significant effect during the post-crisis period for all maturities considered except the 1-month maturity. It would appear that during periods of relative calm in financial markets, speculation can inhibit volatility but when markets are more volatile, speculation can make that volatility worse. Some work like Manera et al. (2014) found that speculation is significant and negative in short-maturity WTI crude oil futures and their data span also covered 2008 financial period, but they do not run regressions in sub-sample periods or look at longer maturities. This indicates that doing so and dividing data in sub-samples or using rolling regressions gives much more insight about the true nature of the effects of certain variables on commodity market volatility.

Table 3.1 WTI Crude Oil 1-Month Maturity Futures Volatility

This table presents regression result of determinants of volatility estimated using the model;

$$\sigma_{i,t} = \alpha + \beta tv_{i,t} + \gamma oi_{i,t} + \theta inv_{t-1} + \delta spec_t + \varepsilon_t$$

Inventory is the US ending stocks of Crude oil and petroleum products, open interest is the number of open contracts with 1-month maturity, trading volume is the number of 1-month maturity contracts traded and speculators is the market share of non-commercial traders. Panel (a) shows result from full sample period that covers data from October 1992 to April 2012, Panel (b) covers data from pre-crisis period between October 1992 and September 2008, and Panel (c) covers post-crisis period with a data span from September 2008 to April 2012. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel (a): Full Period										
	0.0534	0.0536	0.0536	0.0536	0.0534	0.0534	0.0535	0.0534	0.0537	0.0536
c	*0.0010*	*0.0010*	*0.0010*	*0.0009*	*0.0010*	*0.0010*	*0.0009*	*0.0010*	*0.0009*	*0.0009*
	56.06	55.94	55.60	57.91	56.02	56.09	58.05	56.00	57.56	57.96
	-0.0618				-0.0616	-0.0657	-0.0336	-0.0675		-0.0388
Inventory	*0.0154*				*0.0154*	*0.0154*	*0.0199*	*0.0152*		*0.0203*
	-4.02				-4.01	-4.27	-1.69	-4.44		-1.91
		-0.0004			-0.0002			-0.0009	-0.0008	-0.0010
Open Interest		*0.0003*			*0.0003*			*0.0004*	*0.0004*	*0.0004*
		-1.17			-0.66			-2.10	-2.15	-2.36
			-0.0000			0.0013		0.0023	0.0020	0.0026
Trading Volume			*0.0009*			*0.0008*		*0.0011*	*0.0009*	*0.0010*
			-0.04			1.66		2.19	2.16	2.67
				-0.0971			-0.0680		-0.1025	-0.0705
Speculators(MS)				*0.0285*			*0.0367*		*0.0279*	*0.0363*
				-3.41			-1.85		-3.67	-1.94
Adj. R2 %	5.05	-0.02	-0.10	5.99	4.98	5.27	6.87	5.53	6.32	7.49
Panel (b): Pre-crisis Period										
	0.0508	0.0522	0.0520	0.0515	0.0508	0.0508	0.0510	0.0508	0.0515	0.0510
c	*0.0008*	*0.0008*	*0.0008*	*0.0006*	*0.0008*	*0.0007*	*0.0007*	*0.0008*	*0.0007*	*0.0007*
	67.23	64.01	65.64	79.36	66.95	67.96	71.59	67.79	78.19	71.33
	-0.1024				-0.1022	-0.1027	-0.0522	-0.1027		-0.0533
Inventory	*0.0150*				*0.0150*	*0.0151*	*0.0177*	*0.0151*		*0.0178*
	-6.83				-6.80	-6.82	-2.96	-6.82		-3.00
		-0.0006			-0.0001			-0.0002	-0.0003	-0.0002
Open Interest		*0.0003*			*0.0003*			*0.0003*	*0.0003*	*0.0003*
		-2.09			-0.38			-0.46	-0.88	-0.76
			-0.0020			0.0001		0.0003	0.0002	0.0008
Trading Volume			*0.0010*			*0.0008*		*0.0009*	*0.0009*	*0.0008*
			-1.97			0.17		0.27	0.27	1.00
				-0.1538			-0.1137		-0.1539	-0.1146
Speculators(MS)				*0.0187*			*0.0222*		*0.0186*	*0.0222*
				-8.25			-5.12		-8.26	-5.16
Adj. R2 %	20.52	0.19	0.84	26.63	20.43	20.43	30.09	20.35	26.50	30.04
Panel (c): Post-crisis Period										
	0.0705	0.0600	0.0599	0.0538	0.0705	0.0704	0.0644	0.0701	0.0536	0.0639
c	*0.0063*	*0.0030*	*0.0030*	*0.0038*	*0.0063*	*0.0063*	*0.0049*	*0.0063*	*0.0041*	*0.0051*
	11.25	20.08	19.81	14.30	11.25	11.22	13.24	11.13	13.09	12.61
	-0.2734				-0.2734	-0.2761	-0.2693	-0.2800		-0.2771
Inventory	*0.1032*				*0.1034*	*0.1027*	*0.0978*	*0.1027*		*0.0976*
	-2.65				-2.65	-2.69	-2.75	-2.73		-2.84
		0.0004			0.0004			-0.0011	0.0000	-0.0014
Open Interest		*0.0007*			*0.0007*			*0.0015*	*0.0017*	*0.0016*
		0.52			0.56			-0.77	0.03	-0.91
			0.0006			0.0013		0.0032	0.0006	0.0038
Trading Volume			*0.0014*			*0.0014*		*0.0032*	*0.0035*	*0.0035*
			0.42			0.93		1.02	0.17	1.10
				0.3254			0.3114		0.3258	0.3158
Speculators(MS)				*0.2301*			*0.1954*		*0.2322*	*0.1993*
				1.41			1.59		1.40	1.58
Adj. R2 %	13.63	-0.47	-0.48	4.48	13.24	13.43	17.78	13.11	3.52	17.43

Table 3.2 WTI Crude Oil 3-Month Maturity Futures Volatility

This table is created the same way as Table 3.1 using 3-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel (a): Full Period										
	0.0444	0.0445	0.0445	0.0445	0.0444	0.0444	0.0444	0.0444	0.0445	0.0445
c	*0.0009*	*0.0008*	*0.0009*	*0.0008*	*0.0009*	*0.0009*	*0.0008*	*0.0009*	*0.0008*	*0.0008*
	50.93	52.41	51.47	52.59	51.17	50.93	52.75	51.15	53.21	52.97
	-0.0382				-0.0302	-0.0391	-0.0163	-0.0305		-0.0099
Inventory	*0.0147*				*0.0156*	*0.0146*	*0.0190*	*0.0156*		*0.0180*
	-2.59				-1.93	-2.67	-0.86	-1.96		-0.55
		-0.0044			-0.0030			-0.0048	-0.0049	-0.0046
Open Interest		*0.0019*			*0.0021*			*0.0025*	*0.0027*	*0.0026*
		-2.30			-1.44			-1.90	-1.81	-1.76
			-0.0003			0.0003		0.0017	0.0017	0.0017
Trading Volume			*0.0007*			*0.0007*		*0.0008*	*0.0008*	*0.0008*
			-0.46			0.42		2.06	2.08	2.07
				-0.0668			-0.0527		-0.0587	-0.0509
Speculators(MS)				*0.0268*			*0.0345*		*0.0288*	*0.0343*
				-2.49			-1.53		-2.04	-1.48
Adj. R2 %	2.38	1.77	-0.06	3.54	3.02	2.31	3.74	3.52	4.77	4.78
Panel (b): Pre-crisis Period										
	0.0413	0.0423	0.0424	0.0419	0.0413	0.0413	0.0415	0.0413	0.0419	0.0415
c	*0.0006*	*0.0006*	*0.0007*	*0.0005*	*0.0006*	*0.0006*	*0.0005*	*0.0006*	*0.0005*	*0.0005*
	73.86	68.01	64.98	80.69	73.89	74.90	80.59	74.32	81.69	81.05
	-0.0882				-0.0826	-0.0878	-0.0461	-0.0825		-0.0423
Inventory	*0.0114*				*0.0119*	*0.0114*	*0.0124*	*0.0120*		*0.0133*
	-7.72				-6.92	-7.67	-3.71	-6.88		-3.19
		-0.0060			-0.0021			-0.0026	-0.0034	-0.0020
Open Interest		*0.0014*			*0.0014*			*0.0016*	*0.0013*	*0.0014*
		-4.18			-1.44			-1.66	-2.54	-1.46
			-0.0013			-0.0002		0.0005	0.0005	0.0005
Trading Volume			*0.0006*			*0.0005*		*0.0005*	*0.0004*	*0.0005*
			-1.95			-0.34		0.96	1.20	1.04
				-0.1309			-0.0955		-0.1236	-0.0943
Speculators(MS)				*0.0179*			*0.0202*		*0.0173*	*0.0197*
				-7.33			-4.74		-7.13	-4.80
Adj. R2 %	22.67	5.91	0.89	28.70	23.19	22.60	32.73	23.21	29.85	33.00
Panel (c): Post-crisis Period										
	0.0627	0.0542	0.0538	0.0475	0.0629	0.0629	0.0570	0.0627	0.0484	0.0572
c	*0.0055*	*0.0028*	*0.0028*	*0.0035*	*0.0053*	*0.0055*	*0.0044*	*0.0053*	*0.0035*	*0.0045*
	11.44	19.16	19.26	13.73	11.81	11.40	13.06	11.93	13.68	12.84
	-0.2455				-0.2325	-0.2423	-0.2418	-0.2325		-0.2301
Inventory	*0.0931*				*0.0872*	*0.0923*	*0.0878*	*0.0863*		*0.0835*
	-2.64				-2.67	-2.62	-2.75	-2.69		-2.75
		-0.0088			-0.0066			-0.0094	-0.0107	-0.0085
Open Interest		*0.0056*			*0.0045*			*0.0072*	*0.0077*	*0.0068*
		-1.59			-1.47			-1.30	-1.40	-1.25
			-0.0028			-0.0017		0.0028	0.0026	0.0026
Trading Volume			*0.0031*			*0.0026*		*0.0044*	*0.0044*	*0.0041*
			-0.92			-0.64		0.65	0.59	0.62
				0.3032			0.2907		0.2858	0.2780
Speculators(MS)				*0.2021*			*0.1689*		*0.1892*	*0.1645*
				1.50			1.72		1.51	1.69
Adj. R2 %	14.21	3.35	0.26	5.08	15.87	14.03	18.94	15.84	7.76	20.16

Table 3.3 WTI Crude Oil 6-Month Maturity Futures Volatility

This table is created the same way as Table 3.1 using 6-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

					Panel (a): Full Period					
Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	0.0380	0.0381	0.0381	0.0381	0.0380	0.0380	0.0381	0.0380	0.0381	0.0381
c	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*
	42.09	43.21	42.53	43.20	42.23	41.99	43.52	42.49	43.51	44.00
	-0.0153				-0.0116	-0.0201	-0.0036	-0.0185		-0.0048
Inventory	*0.0144*				*0.0147*	*0.0142*	*0.0202*	*0.0142*		*0.0205*
	-1.07				-0.79	-1.41	-0.18	-1.30		-0.23
		-0.0019			-0.0017			-0.0042	-0.0044	-0.0043
Open Interest		*0.0014*			*0.0014*			*0.0018*	*0.0018*	*0.0018*
		-1.36			-1.16			-2.40	-2.48	-2.46
			0.0006			0.0009		0.0023	0.0023	0.0024
Trading Volume			*0.0006*			*0.0006*		*0.0008*	*0.0007*	*0.0007*
			0.94			1.46		2.99	3.33	3.31
				-0.0314			-0.0283		-0.0377	-0.0338
Speculators(MS)				*0.0278*			*0.0374*		*0.0267*	*0.0362*
				-1.13			-0.76		-1.41	-0.93
Adj. R2 %	0.28	0.56	0.11	0.66	0.66	0.61	0.58	2.46	2.99	2.92
					Panel (b): Pre-crisis Period					
	0.0347	0.0355	0.0355	0.0352	0.0347	0.0347	0.0348	0.0347	0.0352	0.0348
c	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*
	59.47	56.51	55.06	63.11	59.61	59.47	62.94	58.52	62.13	61.99
	-0.0690				-0.0661	-0.0679	-0.0364	-0.0663		-0.0338
Inventory	*0.0107*				*0.0111*	*0.0109*	*0.0131*	*0.0111*		*0.0137*
	-6.43				-5.98	-6.23	-2.78	-5.96		-2.47
		-0.0026			-0.0012			-0.0014	-0.0020	-0.0016
Open Interest		*0.0010*			*0.0010*			*0.0011*	*0.0011*	*0.0011*
		-2.64			-1.24			-1.28	-1.85	-1.44
			-0.0010			-0.0003		0.0001	0.0003	0.0004
Trading Volume			*0.0004*			*0.0004*		*0.0004*	*0.0004*	*0.0004*
			-2.37			-0.70		0.38	0.77	0.93
				-0.1019			-0.0740		-0.0995	-0.0746
Speculators(MS)				*0.0188*			*0.0229*		*0.0189*	*0.0230*
				-5.41			-3.23		-5.27	-3.25
Adj. R2 %	14.74	2.34	1.14	18.48	15.12	14.73	21.12	15.03	19.31	21.50
					Panel (c): Post-crisis Period					
	0.0590	0.0491	0.0494	0.0427	0.0592	0.0597	0.0529	0.0586	0.0422	0.0527
c	*0.0058*	*0.0026*	*0.0028*	*0.0033*	*0.0057*	*0.0058*	*0.0043*	*0.0060*	*0.0032*	*0.0045*
	10.22	18.65	17.55	13.05	10.37	10.23	12.17	9.76	13.29	11.75
	-0.2629				-0.2609	-0.2641	-0.2588	-0.2589		-0.2555
Inventory	*0.1004*				*0.0991*	*0.0995*	*0.0932*	*0.1006*		*0.0945*
	-2.62				-2.63	-2.66	-2.78	-2.57		-2.70
		-0.0034			-0.0031			-0.0044	-0.0054	-0.0038
Open Interest		*0.0032*			*0.0027*			*0.0041*	*0.0043*	*0.0038*
		-1.06			-1.11			-1.06	-1.26	-0.98
			-0.0011			-0.0014		0.0013	0.0025	0.0012
Trading Volume			*0.0020*			*0.0017*		*0.0026*	*0.0024*	*0.0023*
			-0.57			-0.81		0.52	1.03	0.51
				0.3242			0.3108		0.3131	0.3017
Speculators(MS)				*0.1996*			*0.1618*		*0.2008*	*0.1642*
				1.62			1.92		1.56	1.84
Adj. R2 %	16.15	0.85	-0.29	5.81	16.84	16.09	21.56	16.52	6.24	21.61

Table 3.4 WTI Crude Oil 12-Month Maturity Futures Volatility

This table is created the same way as Table 3.1 using 12-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel (a): Full Period										
	0.0319	0.0318	0.0321	0.0318	0.0319	0.0321	0.0319	0.0322	0.0322	0.0323
c	*0.0009*	*0.0009*	*0.0010*	*0.0009*	*0.0009*	*0.0010*	*0.0009*	*0.0010*	*0.0010*	*0.0010*
	33.58	34.39	32.97	34.38	33.63	32.68	34.81	32.59	33.43	33.94
	0.0168				0.0191	0.0132	0.0293	0.0149		0.0272
Inventory	*0.0149*				*0.0155*	*0.0154*	*0.0216*	*0.0154*		*0.0235*
	1.13				1.23	0.86	1.36	0.97		1.16
		-0.0004			-0.0007			-0.0020	-0.0019	-0.0021
Open Interest		*0.0010*			*0.0011*			*0.0012*	*0.0012*	*0.0012*
		-0.44			-0.66			-1.64	-1.59	-1.71
			0.0004			0.0003		0.0008	0.0009	0.0009
Trading Volume			*0.0003*			*0.0003*		*0.0004*	*0.0003*	*0.0004*
			1.13			0.92		2.22	2.63	2.44
				-0.0047			-0.0301		-0.0072	-0.0300
Speculators(MS)				*0.0279*			*0.0387*		*0.0284*	*0.0407*
				-0.17			-0.78		-0.25	-0.74
Adj. R2 %	0.33	-0.02	0.21	-0.08	0.42	0.35	0.66	1.18	0.90	1.47
Panel (b): Pre-crisis Period										
	0.0281	0.0287	0.0287	0.0283	0.0281	0.0281	0.0282	0.0281	0.0284	0.0283
c	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*
	44.63	46.11	44.73	49.30	44.59	44.90	47.52	44.44	48.85	47.56
	-0.0442				-0.0433	-0.0455	-0.0098	-0.0465		-0.0117
Inventory	*0.0101*				*0.0106*	*0.0103*	*0.0133*	*0.0106*		*0.0140*
	-4.36				-4.08	-4.41	-0.74	-4.37		-0.83
		-0.0009			-0.0002			0.0004	0.0000	0.0002
Open Interest		*0.0007*			*0.0006*			*0.0007*	*0.0006*	*0.0007*
		-1.33			-0.36			0.61	0.03	0.23
			-0.0005			-0.0004		-0.0005	-0.0004	-0.0004
Trading Volume			*0.0002*			*0.0002*		*0.0002*	*0.0002*	*0.0002*
			-2.38			-1.83		-2.57	-2.09	-2.14
				-0.0855			-0.0780		-0.0869	-0.0782
Speculators(MS)				*0.0180*			*0.0232*		*0.0183*	*0.0237*
				-4.76			-3.36		-4.76	-3.29
Adj. R2 %	6.81	0.58	1.39	14.77	6.74	8.31	14.89	8.30	16.04	16.23
Panel (c): Post-crisis Period										
	0.0550	0.0455	0.0463	0.0392	0.0553	0.0557	0.0489	0.0551	0.0402	0.0493
c	*0.0057*	*0.0026*	*0.0029*	*0.0033*	*0.0056*	*0.0056*	*0.0043*	*0.0055*	*0.0036*	*0.0043*
	9.71	17.67	16.16	11.91	9.85	9.94	11.35	10.05	11.15	11.40
	-0.2504				-0.2527	-0.2478	-0.2464	-0.2541		-0.2479
Inventory	*0.0995*				*0.0980*	*0.0998*	*0.0921*	*0.1006*		*0.0935*
	-2.52				-2.58	-2.48	-2.67	-2.53		-2.65
		-0.0018			-0.0021			-0.0026	0.0001	-0.0018
Open Interest		*0.0027*			*0.0022*			*0.0033*	*0.0036*	*0.0031*
		-0.69			-0.96			-0.78	0.02	-0.59
			-0.0013			-0.0010		0.0004	-0.0015	-0.0002
Trading Volume			*0.0015*			*0.0013*		*0.0019*	*0.0019*	*0.0018*
			-0.87			-0.76		0.20	-0.80	-0.09
				0.3210			0.3082		0.3260	0.3062
Speculators(MS)				*0.1964*			*0.1603*		*0.1944*	*0.1577*
				1.63			1.92		1.68	1.94
Adj. R2 %	15.50	0.28	0.41	6.05	16.14	15.60	21.14	15.72	6.18	21.28

Table 3.5 WTI Crude Oil 18-Month Maturity Futures Volatility

This table is created the same way as Table 3.1 using 18-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel (a): Full Period										
	0.0288	0.0287	0.0305	0.0287	0.0288	0.0304	0.0288	0.0309	0.0310	0.0309
c	*0.0009*	*0.0009*	*0.0011*	*0.0009*	*0.0009*	*0.0010*	*0.0009*	*0.0011*	*0.0011*	*0.0011*
	30.37	30.90	28.14	30.92	30.35	28.95	31.45	28.86	29.04	29.36
	0.0326				0.0324	0.0463	0.0429	0.0457		0.0577
Inventory	*0.0151*				*0.0151*	*0.0164*	*0.0216*	*0.0160*		*0.0260*
	2.16				2.15	2.82	1.98	2.85		2.22
		-0.0004			-0.0004			-0.0015	-0.0016	-0.0015
Open Interest		*0.0005*			*0.0005*			*0.0006*	*0.0006*	*0.0006*
		-0.79			-0.73			-2.56	-2.67	-2.57
			-0.0008			-0.0008		-0.0002	-0.0001	-0.0002
Trading Volume			*0.0004*			*0.0004*		*0.0004*	*0.0004*	*0.0004*
			-1.80			-1.81		-0.36	-0.30	-0.47
				0.0123			-0.0249		0.0197	-0.0292
Speculators(MS)				*0.0272*			*0.0378*		*0.0302*	*0.0449*
				0.45			-0.66		0.65	-0.65
Adj. R2 %	1.55	0.10	1.55	0.01	1.63	4.02	1.75	5.55	3.22	5.73
Panel (b): Pre-crisis Period										
	0.0250	0.0254	0.0258	0.0251	0.0250	0.0253	0.0251	0.0257	0.0257	0.0257
c	*0.0007*	*0.0006*	*0.0007*	*0.0006*	*0.0007*	*0.0007*	*0.0006*	*0.0008*	*0.0007*	*0.0007*
	37.26	39.99	36.24	40.90	37.23	34.94	39.30	33.01	36.49	35.99
	-0.0301				-0.0301	-0.0398	0.0014	-0.0380		0.0017
Inventory	*0.0106*				*0.0105*	*0.0118*	*0.0140*	*0.0117*		*0.0158*
	-2.85				-2.86	-3.37	0.10	-3.25		0.11
		0.0001			0.0001			-0.0008	-0.0007	-0.0007
Open Interest		*0.0003*			*0.0003*			*0.0004*	*0.0004*	*0.0004*
		0.39			0.45			-1.85	-1.90	-1.90
			0.0001			0.0002		0.0005	0.0004	0.0004
Trading Volume			*0.0003*			*0.0003*		*0.0003*	*0.0003*	*0.0003*
			0.55			0.79		1.72	1.37	1.33
				-0.0703			-0.0713		-0.0865	-0.0877
Speculators(MS)				*0.0177*			*0.0234*		*0.0194*	*0.0258*
				-3.98			-3.05		-4.45	-3.40
Adj. R2 %	6.81	0.58	1.39	14.77	6.74	8.31	14.89	8.30	16.04	16.23
Panel (c): Post-crisis Period										
	0.0518	0.0428	0.0419	0.0370	0.0516	0.0493	0.0458	0.0498	0.0380	0.0460
c	*0.0052*	*0.0023*	*0.0021*	*0.0031*	*0.0052*	*0.0053*	*0.0040*	*0.0052*	*0.0031*	*0.0042*
	9.87	18.38	19.92	11.79	9.83	9.27	11.33	9.65	12.35	10.91
	-0.2273				-0.2250	-0.1889	-0.2234	-0.2024		-0.1991
Inventory	*0.0923*				*0.0920*	*0.0980*	*0.0850*	*0.0959*		*0.0919*
	-2.46				-2.45	-1.93	-2.63	-2.11		-2.17
		-0.0012			-0.0006			0.0050	0.0034	0.0043
Open Interest		*0.0016*			*0.0015*			*0.0025*	*0.0023*	*0.0022*
		-0.73			-0.42			1.99	1.49	1.94
			-0.0014			-0.0014		-0.0033	-0.0025	-0.0028
Trading Volume			*0.0008*			*0.0007*		*0.0011*	*0.0011*	*0.0010*
			-1.85			-2.02		-2.90	-2.34	-2.80
				0.3149			0.3033		0.2174	0.2046
Speculators(MS)				*0.1835*			*0.1509*		*0.1788*	*0.1567*
				1.72			2.01		1.22	1.31
Adj. R2 %	14.74	0.08	4.07	6.79	14.46	13.93	21.11	17.97	9.54	20.58

Table 3.6 WTI Crude Oil 1-Month Maturity Futures Volatility Robustness Results

This table presents regression result of determinants of volatility using the same model as in Table 3.1 but using different volatility and speculators variables as robustness analysis.

Inventory is the US ending stocks of Crude oil and petroleum products, open interest is the number of open contracts with 1-month maturity and trading volume is the number of 1-month maturity contracts traded same as that used in Table 3.1. The volatility variable is calculated by Parkinson (1980)'s High-Low volatility estimator model as given in equation (3.7). The Working T index is the speculators variable calculated using equation (3.2). Panel (a) shows result from full sample period that covers data from October 1992 to April 2012, Panel (b) covers data from pre-crisis period between October 1992 and September 2008, and Panel (c) covers post-crisis period with a data span from September 2008 to April 2012. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel (a): Full Period										
	0.0455	0.0457	0.0457	0.0461	0.0455	0.0455	0.0459	0.0455	0.0462	0.0459
c	*0.0014*	*0.0014*	*0.0014*	*0.0014*	*0.0014*	*0.0014*	*0.0014*	*0.0014*	*0.0014*	*0.0014*
	31.79	31.97	31.75	32.37	31.77	31.73	33.26	31.66	32.46	33.35
	-0.0738				-0.0735	-0.0768	-0.0785	-0.0785		-0.0809
Inventory	*0.0239*				*0.0238*	*0.0237*	*0.0305*	*0.0235*		*0.0305*
	-3.10				-3.08	-3.24	-2.57	-3.34		-2.65
		-0.0005			-0.0003			-0.0009	-0.0008	-0.0010
Open Interest		*0.0004*			*0.0004*			*0.0005*	*0.0005*	*0.0005*
		-1.04			-0.62			-1.60	-1.65	-1.99
			-0.0006			0.0010		0.0020	0.0012	0.0021
Trading Volume			*0.0013*			*0.0011*		*0.0013*	*0.0012*	*0.0011*
			-0.48			0.90		1.45	1.06	1.84
				-0.0207			0.0189		-0.0232	0.0154
Working T				*0.0351*			*0.0422*		*0.0355*	*0.0423*
				-0.59			0.45		-0.65	0.36
Adj. R2 %	3.36	-0.03	-0.06	0.27	3.29	3.35	2.82	3.41	0.21	2.90
Panel (b): Pre-crisis Period										
	0.0418	0.0435	0.0432	0.0428	0.0418	0.0417	0.0419	0.0417	0.0428	0.0420
c	*0.0009*	*0.0010*	*0.0010*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*	*0.0009*
	45.91	41.91	43.01	46.94	45.75	46.39	47.94	46.33	46.72	48.09
	-0.1316				-0.1315	-0.1309	-0.0887	-0.1309		-0.0892
Inventory	*0.0206*				*0.0206*	*0.0208*	*0.0247*	*0.0208*		*0.0247*
	-6.39				-6.40	-6.31	-3.59	-6.30		-3.62
		-0.0007			0.0000			0.0001	-0.0004	-0.0002
Open Interest		*0.0004*			*0.0003*			*0.0004*	*0.0004*	*0.0003*
		-1.79			-0.07			0.14	-1.02	-0.57
			-0.0031			-0.0003		-0.0003	0.0008	0.0011
Trading Volume			*0.0013*			*0.0010*		*0.0012*	*0.0011*	*0.0010*
			-2.33			-0.28		-0.28	0.75	1.07
				-0.1035			-0.0589		-0.1053	-0.0613
Working T				*0.0189*			*0.0205*		*0.0189*	*0.0203*
				-5.47			-2.87		-5.57	-3.02
Adj. R2 %	23.02	0.13	1.36	20.62	22.93	22.94	27.19	22.85	20.53	27.14
Panel (c): Post-crisis Period										
	0.0720	0.0580	0.0581	0.0485	0.0720	0.0719	0.0606	0.0719	0.0489	0.0604
c	*0.0096*	*0.0048*	*0.0049*	*0.0029*	*0.0096*	*0.0097*	*0.0070*	*0.0098*	*0.0035*	*0.0072*
	7.48	11.97	11.88	16.99	7.46	7.44	8.70	7.31	14.09	8.39
	-0.3712				-0.3712	-0.3723	-0.2982	-0.3723		-0.3000
Inventory	*0.1511*				*0.1515*	*0.1511*	*0.1370*	*0.1501*		*0.1372*
	-2.46				-2.45	-2.46	-2.18	-2.48		-2.19
		0.0002			0.0003			0.0000	0.0007	-0.0008
Open Interest		*0.0010*			*0.0010*			*0.0025*	*0.0027*	*0.0025*
		0.22			0.25			0.00	0.28	-0.30
			-0.0004			0.0005		0.0005	-0.0024	0.0010
Trading Volume			*0.0021*			*0.0022*		*0.0051*	*0.0056*	*0.0057*
			-0.22			0.25		0.10	-0.42	0.18
				0.3335			0.3018		0.3335	0.3026
Working T				*0.1116*			*0.0981*		*0.1121*	*0.0993*
				2.99			3.08		2.97	3.05
Adj. R2 %	9.73	-0.52	-0.52	18.29	9.26	9.26	24.34	8.77	17.51	23.55

Table 3.7 WTI Crude Oil 3-Month Maturity Futures Volatility Robustness Results

This table is created the same way as Table 3.6 using 3-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Panel (a): Full Period										
Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	0.0379	0.0380	0.0380	0.0384	0.0379	0.0379	0.0383	0.0379	0.0384	0.0383
c	*0.0011*	*0.0011*	*0.0011*	*0.0011*	*0.0011*	*0.0011*	*0.0011*	*0.0011*	*0.0011*	*0.0011*
	33.95	34.67	34.25	34.90	34.06	33.90	35.55	33.97	35.33	35.63
	-0.0452				-0.0367	-0.0448	-0.0412	-0.0369		-0.0341
Inventory	*0.0188*				*0.0193*	*0.0186*	*0.0251*	*0.0193*		*0.0234*
	-2.41				-1.90	-2.41	-1.64	-1.91		-1.46
		-0.0049			-0.0031			-0.0043	-0.0052	-0.0042
Open Interest		*0.0024*			*0.0025*			*0.0031*	*0.0034*	*0.0032*
		-2.06			-1.28			-1.41	-1.54	-1.31
			-0.0009			-0.0001		0.0011	0.0011	0.0010
Trading Volume			*0.0009*			*0.0008*		*0.0010*	*0.0010*	*0.0010*
			-0.99			-0.18		1.07	1.06	1.04
				-0.0164			0.0044		-0.0095	0.0059
Working T				*0.0276*			*0.0341*		*0.0292*	*0.0341*
				-0.59			0.13		-0.33	0.17
Adj. R2 %	2.07	1.34	0.05	0.29	2.48	1.98	1.42	2.55	1.18	1.87
Panel (b): Pre-crisis Period										
	0.0343	0.0354	0.0355	0.0351	0.0343	0.0343	0.0345	0.0343	0.0350	0.0345
c	*0.0007*	*0.0008*	*0.0008*	*0.0008*	*0.0007*	*0.0007*	*0.0007*	*0.0007*	*0.0007*	*0.0007*
	46.34	45.08	43.45	46.75	46.44	46.83	49.27	46.57	47.43	49.44
	-0.1040				-0.0978	-0.1021	-0.0635	-0.0978		-0.0610
Inventory	*0.0147*				*0.0146*	*0.0148*	*0.0191*	*0.0146*		*0.0193*
	-7.07				-6.69	-6.89	-3.33	-6.71		-3.16
		-0.0070			-0.0023			-0.0021	-0.0029	-0.0013
Open Interest		*0.0018*			*0.0016*			*0.0020*	*0.0018*	*0.0017*
		-3.86			-1.41			-1.08	-1.63	-0.73
			-0.0019			-0.0007		-0.0001	0.0002	0.0000
Trading Volume			*0.0007*			*0.0006*		*0.0007*	*0.0007*	*0.0007*
			-2.90			-1.17		-0.18	0.24	0.02
				-0.0875			-0.0556		-0.0820	-0.0543
Working T				*0.0189*			*0.0222*		*0.0189*	*0.0220*
				-4.63			-2.50		-4.34	-2.47
Adj. R2 %	21.99	5.50	1.57	22.55	22.42	22.09	27.69	22.33	23.16	27.67
Panel (c): Post-crisis Period										
	0.0608	0.0515	0.0512	0.0435	0.0611	0.0611	0.0526	0.0610	0.0444	0.0529
c	*0.0068*	*0.0035*	*0.0034*	*0.0020*	*0.0067*	*0.0068*	*0.0049*	*0.0067*	*0.0021*	*0.0049*
	8.94	14.82	15.00	21.65	9.11	8.99	10.65	9.14	21.15	10.79
	-0.2751				-0.2617	-0.2698	-0.2218	-0.2617		-0.2148
Inventory	*0.1128*				*0.1079*	*0.1117*	*0.1004*	*0.1081*		*0.0994*
	-2.44				-2.43	-2.42	-2.21	-2.42		-2.16
		-0.0094			-0.0069			-0.0079	-0.0057	-0.0041
Open Interest		*0.0063*			*0.0052*			*0.0089*	*0.0081*	*0.0078*
		-1.50			-1.31			-0.88	-0.71	-0.52
			-0.0040			-0.0028		0.0010	-0.0002	-0.0001
Trading Volume			*0.0039*			*0.0035*		*0.0060*	*0.0052*	*0.0052*
			-1.04			-0.80		0.17	-0.05	-0.03
				0.2439			0.2203		0.2363	0.2157
Working T				*0.0763*			*0.0646*		*0.0734*	*0.0634*
				3.19			3.41		3.22	3.40
Adj. R2 %	11.47	2.30	0.53	20.90	12.49	11.50	28.12	12.05	21.18	27.90

Table 3.8 WTI Crude Oil 6-Month Maturity Futures Volatility Robustness Results

This table is created the same way as Table 3.6 using 6-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

					Panel (a): Full Period					
Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	0.0297	0.0297	0.0298	0.0300	0.0297	0.0297	0.0300	0.0297	0.0301	0.0300
c	*0.0010*	*0.0010*	*0.0010*	*0.0010*	*0.0010*	*0.0010*	*0.0010*	*0.0010*	*0.0010*	*0.0010*
	30.00	30.55	30.39	30.99	29.97	30.00	31.35	30.07	30.94	31.39
	-0.0047				-0.0045	-0.0105	-0.0098	-0.0097		-0.0134
Inventory	*0.0162*				*0.0167*	*0.0160*	*0.0227*	*0.0161*		*0.0235*
	-0.29				-0.27	-0.65	-0.43	-0.60		-0.57
		-0.0002			-0.0001			-0.0020	-0.0021	-0.0021
Open Interest		*0.0016*			*0.0017*			*0.0020*	*0.0019*	*0.0019*
		-0.11			-0.05			-1.00	-1.11	-1.07
			0.0009			0.0010		0.0017	0.0017	0.0018
Trading Volume			*0.0007*			*0.0007*		*0.0008*	*0.0008*	*0.0008*
			1.17			1.40		2.01	2.19	2.25
				0.0116			0.0165		0.0078	0.0141
Working T				*0.0233*			*0.0299*		*0.0226*	*0.0291*
				0.50			0.55		0.35	0.49
Adj. R2 %	-0.07	-0.09	0.32	0.15	-0.16	0.36	0.14	0.63	0.88	0.94
					Panel (b): Pre-crisis Period					
	0.0261	0.0269	0.0268	0.0266	0.0261	0.0261	0.0262	0.0261	0.0266	0.0262
c	*0.0007*	*0.0007*	*0.0007*	*0.0007*	*0.0007*	*0.0007*	*0.0006*	*0.0007*	*0.0007*	*0.0006*
	39.63	39.30	38.41	38.94	39.63	39.44	41.37	38.95	38.49	40.63
	-0.0637				-0.0628	-0.0620	-0.0405	-0.0621		-0.0401
Inventory	*0.0118*				*0.0121*	*0.0120*	*0.0179*	*0.0122*		*0.0182*
	-5.41				-5.18	-5.15	-2.27	-5.10		-2.21
		-0.0017			-0.0003			0.0001	-0.0003	0.0001
Open Interest		*0.0012*			*0.0011*			*0.0012*	*0.0013*	*0.0013*
		-1.47			-0.30			0.12	-0.20	0.10
			-0.0010			-0.0004		-0.0004	-0.0003	-0.0002
Trading Volume			*0.0005*			*0.0005*		*0.0004*	*0.0004*	*0.0004*
			-2.16			-0.80		-0.92	-0.67	-0.55
				-0.0522			-0.0318		-0.0506	-0.0313
Working T				*0.0171*			*0.0218*		*0.0174*	*0.0220*
				-3.06			-1.46		-2.90	-1.43
Adj. R2 %	11.96	0.85	1.21	11.62	11.89	12.02	14.61	11.91	11.60	14.46
					Panel (c): Post-crisis Period					
	0.0523	0.0435	0.0434	0.0378	0.0523	0.0522	0.0456	0.0524	0.0370	0.0451
c	*0.0055*	*0.0026*	*0.0024*	*0.0017*	*0.0054*	*0.0052*	*0.0040*	*0.0056*	*0.0017*	*0.0041*
	9.54	16.63	17.94	22.26	9.62	10.00	11.41	9.44	22.02	11.07
	-0.2329				-0.2332	-0.2327	-0.1894	-0.2336		-0.1885
Inventory	*0.0906*				*0.0915*	*0.0903*	*0.0796*	*0.0921*		*0.0801*
	-2.57				-2.55	-2.58	-2.38	-2.54		-2.35
		0.0002			0.0004			0.0007	-0.0008	0.0004
Open Interest		*0.0031*			*0.0027*			*0.0046*	*0.0042*	*0.0039*
		0.05			0.16			0.16	-0.18	0.11
			0.0004			0.0002		-0.0003	0.0018	0.0008
Trading Volume			*0.0018*			*0.0016*		*0.0028*	*0.0025*	*0.0024*
			0.23			0.10		-0.10	0.73	0.33
				0.1999			0.1797		0.2021	0.1815
Working T				*0.0616*			*0.0519*		*0.0633*	*0.0531*
				3.25			3.46		3.19	3.42
Adj. R2 %	12.69	-0.53	-0.50	21.60	12.25	12.23	29.75	11.78	21.15	29.22

Table 3.9 WTI Crude Oil 12-Month Maturity Futures Volatility Robustness Results

This table is created the same way as Table 3.6 using 12-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Panel (a): Full Period										
Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	0.0213	0.0212	0.0215	0.0214	0.0213	0.0215	0.0215	0.0216	0.0217	0.0217
c	*0.0008*	*0.0008*	*0.0008*	*0.0008*	*0.0008*	*0.0008*	*0.0008*	*0.0009*	*0.0008*	*0.0008*
	25.83	26.21	25.48	26.31	25.87	25.39	26.69	25.36	25.87	26.18
	0.0132				0.0131	0.0099	0.0115	0.0109		0.0059
Inventory	*0.0135*				*0.0142*	*0.0139*	*0.0193*	*0.0141*		*0.0207*
	0.98				0.92	0.71	0.60	0.78		0.29
		0.0002			0.0000			-0.0011	-0.0010	-0.0010
Open Interest		*0.0009*			*0.0009*			*0.0010*	*0.0010*	*0.0010*
		0.23			0.04			-1.05	-0.95	-0.96
			0.0005			0.0005		0.0007	0.0008	0.0007
Trading Volume			*0.0003*			*0.0003*		*0.0003*	*0.0003*	*0.0003*
			1.59			1.40		2.25	2.33	2.23
				0.0144			0.0086		0.0152	0.0124
Working T				*0.0190*			*0.0250*		*0.0193*	*0.0255*
				0.76			0.34		0.79	0.49
Adj. R2 %	0.25	-0.08	0.58	0.44	0.15	0.65	0.52	0.91	1.33	1.27
Panel (b): Pre-crisis Period										
	0.0182	0.0187	0.0187	0.0184	0.0182	0.0183	0.0183	0.0182	0.0184	0.0182
c	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*	*0.0006*
	30.84	30.57	29.49	30.42	30.76	30.45	32.07	30.12	29.82	31.30
	-0.0385				-0.0394	-0.0394	-0.0172	-0.0413		-0.0212
Inventory	*0.0101*				*0.0107*	*0.0106*	*0.0167*	*0.0107*		*0.0170*
	-3.81				-3.70	-3.72	-1.03	-3.85		-1.25
		-0.0003			0.0002			0.0008	0.0007	0.0009
Open Interest		*0.0007*			*0.0007*			*0.0007*	*0.0007*	*0.0007*
		-0.52			0.37			1.09	1.03	1.25
			-0.0003			-0.0002		-0.0004	-0.0004	-0.0004
Trading Volume			*0.0002*			*0.0002*		*0.0002*	*0.0002*	*0.0002*
			-1.37			-0.83		-1.71	-1.91	-1.91
				-0.0379			-0.0292		-0.0377	-0.0276
Working T				*0.0148*			*0.0204*		*0.0156*	*0.0207*
				-2.56			-1.44		-2.42	-1.33
Adj. R2 %	5.59	0.00	0.47	7.90	5.54	6.10	8.51	6.35	8.01	8.94
Panel (c): Post-crisis Period										
	0.0396	0.0334	0.0334	0.0291	0.0395	0.0394	0.0344	0.0396	0.0296	0.0344
c	*0.0042*	*0.0020*	*0.0022*	*0.0015*	*0.0042*	*0.0042*	*0.0032*	*0.0043*	*0.0018*	*0.0033*
	9.44	16.70	15.34	19.92	9.50	9.45	10.85	9.17	16.36	10.29
	-0.1627				-0.1622	-0.1631	-0.1295	-0.1614		-0.1264
Inventory	*0.0686*				*0.0682*	*0.0693*	*0.0591*	*0.0681*		*0.0570*
	-2.37				-2.38	-2.35	-2.19	-2.37		-2.22
		0.0007			0.0005			0.0007	0.0025	0.0015
Open Interest		*0.0021*			*0.0018*			*0.0028*	*0.0027*	*0.0023*
		0.31			0.26			0.25	0.94	0.66
			0.0000			0.0002		-0.0002	-0.0010	-0.0004
Trading Volume			*0.0012*			*0.0010*		*0.0015*	*0.0015*	*0.0014*
			-0.01			0.17		-0.13	-0.66	-0.27
				0.1508			0.1370		0.1531	0.1393
Working T				*0.0466*			*0.0402*		*0.0470*	*0.0407*
				3.24			3.41		3.26	3.42
Adj. R2 %	10.58	-0.37	-0.53	21.16	10.18	10.13	27.64	9.71	21.31	27.37

Table 3.10 WTI Crude Oil 18-Month Maturity Futures Volatility Robustness Results

This table is created the same way as Table 3.6 using 18-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

Panel (a): Full Period										
Predictor Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	0.0177	0.0177	0.0188	0.0179	0.0177	0.0188	0.0178	0.0191	0.0193	0.0193
c	*0.0007*	*0.0007*	*0.0008*	*0.0007*	*0.0007*	*0.0008*	*0.0007*	*0.0008*	*0.0007*	*0.0007*
	26.29	26.72	23.44	27.14	26.26	24.07	27.39	24.43	26.54	26.24
	0.0071				0.0071	0.0198	-0.0015	0.0193		0.0050
Inventory	*0.0120*				*0.0121*	*0.0137*	*0.0178*	*0.0135*		*0.0194*
	0.59				0.59	1.44	-0.09	1.43		0.26
		0.0000			0.0000			-0.0009	-0.0011	-0.0011
Open Interest		*0.0003*			*0.0003*			*0.0004*	*0.0004*	*0.0004*
		-0.07			-0.05			-2.32	-2.52	-2.47
			-0.0002			-0.0002		0.0002	0.0003	0.0003
Trading Volume			*0.0003*			*0.0003*		*0.0003*	*0.0003*	*0.0003*
			-0.60			-0.60		0.61	0.96	0.96
				0.0181			0.0189		0.0293	0.0268
Working T				*0.0159*			*0.0212*		*0.0170*	*0.0230*
				1.13			0.89		1.72	1.17
Adj. R2 %	0.06	-0.10	0.03	1.20	-0.04	0.84	1.11	2.00	4.04	3.93
Panel (b): Pre-crisis Period										
	0.0152	0.0157	0.0158	0.0155	0.0152	0.0153	0.0153	0.0155	0.0158	0.0155
c	*0.0005*	*0.0005*	*0.0006*	*0.0006*	*0.0005*	*0.0005*	*0.0005*	*0.0006*	*0.0006*	*0.0006*
	29.33	29.92	27.83	28.07	29.41	28.42	30.38	27.59	25.24	27.76
	-0.0359				-0.0359	-0.0446	-0.0288	-0.0435		-0.0344
Inventory	*0.0089*				*0.0089*	*0.0089*	*0.0165*	*0.0088*		*0.0176*
	-4.04				-4.06	-5.02	-1.75	-4.93		-1.95
		0.0002			0.0002			-0.0004	-0.0004	-0.0004
Open Interest		*0.0002*			*0.0002*			*0.0003*	*0.0003*	*0.0003*
		0.65			0.75			-1.55	-1.47	-1.45
			0.0002			0.0003		0.0005	0.0004	0.0005
Trading Volume			*0.0002*			*0.0002*		*0.0002*	*0.0002*	*0.0002*
			1.12			1.46		2.07	1.72	1.88
				-0.0242			-0.0097		-0.0286	-0.0123
Working T				*0.0144*			*0.0197*		*0.0150*	*0.0203*
				-1.68			-0.49		-1.90	-0.61
Adj. R2 %	6.70	0.01	0.44	4.38	6.73	9.73	7.04	10.20	7.28	10.73
Panel (c): Post-crisis Period										
	0.0314	0.0276	0.0270	0.0234	0.0318	0.0300	0.0265	0.0305	0.0239	0.0267
c	*0.0033*	*0.0015*	*0.0014*	*0.0011*	*0.0034*	*0.0035*	*0.0024*	*0.0033*	*0.0011*	*0.0025*
	9.40	18.05	19.06	21.54	9.28	8.64	11.05	9.29	21.73	10.64
	-0.1064				-0.1113	-0.0786	-0.0751	-0.0916		-0.0687
Inventory	*0.0589*				*0.0603*	*0.0633*	*0.0453*	*0.0599*		*0.0474*
	-1.81				-1.85	-1.24	-1.66	-1.53		-1.45
		0.0011			0.0014			0.0048	0.0028	0.0032
Open Interest		*0.0009*			*0.0009*			*0.0015*	*0.0013*	*0.0012*
		1.17			1.59			3.11	2.19	2.58
			-0.0002			-0.0002		-0.0020	-0.0009	-0.0011
Trading Volume			*0.0005*			*0.0004*		*0.0007*	*0.0005*	*0.0005*
			-0.38			-0.36		-2.91	-1.83	-2.15
				0.1375			0.1295		0.1224	0.1161
Working T				*0.0318*			*0.0270*		*0.0330*	*0.0281*
				4.32			4.80		3.71	4.14
Adj. R2 %	7.54	0.76	-0.40	30.09	9.03	3.47	33.65	13.04	30.38	33.32

Table 3.11 WTI Crude Oil 1-Month Maturity Futures Volatility Forecast

This table presents the result of ability of the explanatory variables to forecast volatility estimated using the model;

$$\sigma_{i,t} = \alpha + \sigma_{i,t-1} + \beta tv_{i,t-1} + \gamma oi_{i,t-1} + \theta inv_{t-1} + \delta spec_{t-1} + \varepsilon_t$$

Inventory is the US ending stocks of Crude oil and petroleum products, open interest is the number of open contracts with 1-month maturity, trading volume is the number of 1-month maturity contracts traded and speculators is the market share of non-commercial traders, and all of the variables are lagged one term. Panel (a) shows result from full sample period that covers data from October 1992 to April 2012, Panel (b) covers data from pre-crisis period between October 1992 and September 2008, and Panel (c) covers post-crisis period with a data span from September 2008 to April 2012. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

	Panel (a): Full Period				**Panel (b): Pre-crisis Period**				**Panel (c): Post-crisis Period**			
Predictor Variable	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	0.0534	0.0536	0.0028	0.0028	0.0508	0.0510	0.0049	0.0056	0.0704	0.0640	0.0034	0.0031
c	*0.0010*	*0.0009*	*0.0009*	*0.0009*	*0.0007*	*0.0007*	*0.0012*	*0.0014*	*0.0065*	*0.0050*	*0.0017*	*0.0017*
	56.07	58.07	3.24	2.99	67.86	71.52	4.13	3.97	10.89	12.75	1.98	1.82
	-0.0670	-0.0382	-0.0056	-0.0055	-0.1031	-0.0529	-0.0119	-0.0081	-0.2748	-0.2697	-0.0244	-0.0252
Inventory	*0.0154*	*0.0201*	*0.0030*	*0.0032*	*0.0151*	*0.0176*	*0.0045*	*0.0042*	*0.1015*	*0.0960*	*0.0173*	*0.0172*
	-4.36	-1.90	-1.87	-1.70	-6.85	-3.01	-2.65	-1.96	-2.71	-2.81	-1.41	-1.47
	-0.0006	-0.0007	0.0002	0.0002	0.0001	0.0000	0.0002	0.0002	0.0001	-0.0002	0.0009	0.0009
Open Interest	*0.0004*	*0.0004*	*0.0001*	*0.0001*	*0.0003*	*0.0003*	*0.0001*	*0.0001*	*0.0018*	*0.0018*	*0.0009*	*0.0009*
	-1.52	-1.73	1.63	1.61	0.24	0.05	1.87	1.82	0.07	-0.10	1.03	1.01
	0.0020	0.0023	-0.0001	-0.0001	0.0002	0.0007	-0.0000	0.0000	0.0008	0.0013	-0.0016	-0.0016
Trading Volume	*0.0010*	*0.0009*	*0.0003*	*0.0003*	*0.0009*	*0.0008*	*0.0002*	*0.0002*	*0.0037*	*0.0038*	*0.0017*	*0.0016*
	1.98	2.42	-0.51	-0.50	0.25	0.99	-0.04	0.25	0.20	0.34	-0.98	-0.95
		-0.0704		-0.0002		-0.1162		-0.0118		0.3202		0.0308
Speculators(MS)		*0.0363*		*0.0058*		*0.0223*		*0.0055*		*0.1915*		*0.0266*
		-1.94		-0.04		-5.21		-2.14		1.67		1.16
			0.9475	0.9474			0.9033	0.8903			0.9639	0.9588
Lagged Volatility			*0.0166*	*0.0179*			*0.0237*	*0.0279*			*0.0227*	*0.0231*
			56.97	52.83			38.16	31.89			42.54	41.46
Adj. R2 %	5.35	7.26	90.64	90.61	20.35	30.27	86.15	86.18	12.84	17.35	94.94	94.96

Table 3.12 WTI Crude Oil 3-Month Maturity Futures Volatility Forecast

This table is created the same way as Table 3.6 using 3-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

	Panel (a): Full Period				Panel (b): Pre-crisis Period				Panel (c): Post-crisis Period			
Predictor Variable	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	0.0444	0.0445	0.0018	0.0017	0.0413	0.0415	0.0036	0.0041	0.0629	0.0574	0.0030	0.0028
c	*0.0009*	*0.0008*	*0.0006*	*0.0006*	*0.0006*	*0.0005*	*0.0007*	*0.0008*	*0.0053*	*0.0044*	*0.0014*	*0.0014*
	51.13	52.96	2.97	2.74	74.49	81.22	5.30	4.94	11.93	13.06	2.12	1.99
	-0.0308	-0.0105	-0.0036	-0.0041	-0.0833	-0.0428	-0.0094	-0.0069	-0.2351	-0.2305	-0.0235	-0.0241
Inventory	*0.0160*	*0.0183*	*0.0028*	*0.0033*	*0.0122*	*0.0135*	*0.0039*	*0.0038*	*0.0852*	*0.0810*	*0.0152*	*0.0153*
	-1.93	-0.57	-1.28	-1.25	-6.81	-3.17	-2.40	-1.82	-2.76	-2.85	-1.54	-1.57
	-0.0044	-0.0041	0.0004	0.0004	-0.0020	-0.0014	0.0006	0.0006	-0.0107	-0.0100	-0.0009	-0.0009
Open Interest	*0.0026*	*0.0027*	*0.0004*	*0.0004*	*0.0017*	*0.0015*	*0.0005*	*0.0005*	*0.0070*	*0.0065*	*0.0010*	*0.0009*
	-1.68	-1.53	0.84	0.84	-1.19	-0.94	1.24	1.28	-1.54	-1.54	-0.91	-0.92
	0.0014	0.0013	-0.0003	-0.0003	0.0002	0.0001	-0.0003	-0.0003	0.0028	0.0026	0.0001	0.0001
Trading Volume	*0.0008*	*0.0008*	*0.0002*	*0.0002*	*0.0005*	*0.0005*	*0.0002*	*0.0002*	*0.0041*	*0.0038*	*0.0007*	*0.0007*
	1.71	1.69	-1.57	-1.57	0.37	0.33	-1.97	-2.02	0.69	0.68	0.13	0.13
		-0.0501		0.0012		-0.0950		-0.0082		0.2800		0.0229
Speculators(MS)		*0.0346*		*0.0047*		*0.0199*		*0.0046*		*0.1587*		*0.0227*
		-1.45		0.26		-4.78		-1.76		1.76		1.01
			0.9603	0.9605			0.9121	0.9006			0.9620	0.9575
Lagged Volatility			*0.0137*	*0.0146*			*0.0158*	*0.0192*			*0.0180*	*0.0193*
			70.16	66.01			57.81	46.94			53.49	49.51
Adj. R2 %	3.29	4.47	92.51	92.49	22.96	32.84	87.46	87.47	16.90	21.35	95.38	95.39

Table 3.13 WTI Crude Oil 6-Month Maturity Futures Volatility Forecast

This table is created the same way as Table 3.6 using 6-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

	Panel (a): Full Period				**Panel (b): Pre-crisis Period**				**Panel (c): Post-crisis Period**			
Predictor Variable	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	0.0380	0.0381	0.0016	0.0015	0.0347	0.0348	0.0029	0.0031	0.0587	0.0528	0.0035	0.0033
c	*0.0009*	*0.0009*	*0.0005*	*0.0005*	*0.0006*	*0.0006*	*0.0006*	*0.0007*	*0.0060*	*0.0045*	*0.0015*	*0.0015*
	42.48	43.98	3.01	2.87	58.56	61.94	5.15	4.77	9.73	11.68	2.30	2.25
	-0.0179	-0.0046	-0.0016	-0.0025	-0.0667	-0.0344	-0.0064	-0.0049	-0.2575	-0.2526	-0.0247	-0.0253
Inventory	*0.0143*	*0.0202*	*0.0023*	*0.0030*	*0.0111*	*0.0136*	*0.0029*	*0.0031*	*0.1000*	*0.0941*	*0.0156*	*0.0162*
	-1.25	-0.23	-0.70	-0.85	-6.00	-2.53	-2.20	-1.58	-2.57	-2.68	-1.58	-1.56
	-0.0042	-0.0044	-0.0002	-0.0002	-0.0010	-0.0013	0.0002	0.0002	-0.0050	-0.0044	-0.0008	-0.0008
Open Interest	*0.0018*	*0.0018*	*0.0003*	*0.0003*	*0.0011*	*0.0011*	*0.0003*	*0.0003*	*0.0041*	*0.0038*	*0.0009*	*0.0009*
	-2.37	-2.45	-0.77	-0.75	-0.96	-1.14	0.79	0.68	-1.21	-1.14	-0.83	-0.82
	0.0021	0.0022	-0.0000	-0.0000	0.0000	0.0003	-0.0001	-0.0001	0.0011	0.0010	-0.0004	-0.0004
Trading Volume	*0.0008*	*0.0007*	*0.0001*	*0.0001*	*0.0004*	*0.0004*	*0.0001*	*0.0001*	*0.0026*	*0.0023*	*0.0007*	*0.0007*
	2.82	3.13	-0.16	-0.21	0.12	0.65	-0.80	-0.70	0.43	0.44	-0.66	-0.65
		-0.0319		0.0024		-0.0738		-0.0042		0.2933		0.0171
Speculators(MS)		*0.0362*		*0.0046*		*0.0231*		*0.0044*		*0.1608*		*0.0254*
		-0.88		0.52		-3.20		-0.95		1.82		0.67
			0.9589	0.9592			0.9153	0.9106			0.9527	0.9491
Lagged Volatility			*0.0141*	*0.0144*			*0.0156*	*0.0177*			*0.0220*	*0.0234*
			68.06	66.54			58.64	51.32			43.40	40.57
Adj. R2 %	2.35	2.78	92.21	92.20	14.86	21.14	86.45	86.41	17.18	22.03	94.00	93.99

Table 3.14 WTI Crude Oil 12-Month Maturity Futures Volatility Forecast

This table is created the same way as Table 3.6 using 12-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

	Panel (a): Full Period				**Panel (b): Pre-crisis Period**				**Panel (c): Post-crisis Period**			
Predictor Variable	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	0.0322	0.0323	0.0007	0.0007	0.0281	0.0283	0.0013	0.0014	0.0552	0.0495	0.0028	0.0027
c	*0.0010*	*0.0010*	*0.0004*	*0.0004*	*0.0006*	*0.0006*	*0.0004*	*0.0004*	*0.0054*	*0.0042*	*0.0014*	*0.0013*
	32.52	33.86	2.06	1.94	44.40	47.37	3.64	3.15	10.27	11.75	2.02	2.03
	0.0153	0.0269	-0.0014	-0.0026	-0.0471	-0.0130	-0.0035	-0.0032	-0.2578	-0.2501	-0.0232	-0.0236
Inventory	*0.0153*	*0.0231*	*0.0018*	*0.0026*	*0.0107*	*0.0138*	*0.0023*	*0.0022*	*0.1016*	*0.0946*	*0.0146*	*0.0152*
	1.00	1.16	-0.78	-1.02	-4.40	-0.94	-1.56	-1.43	-2.54	-2.64	-1.58	-1.56
	-0.0020	-0.0020	-0.0000	-0.0000	0.0006	0.0003	0.0002	0.0002	-0.0036	-0.0030	-0.0005	-0.0005
Open Interest	*0.0012*	*0.0012*	*0.0002*	*0.0002*	*0.0007*	*0.0007*	*0.0001*	*0.0001*	*0.0035*	*0.0033*	*0.0007*	*0.0007*
	-1.63	-1.71	-0.16	-0.11	0.86	0.50	1.42	1.45	-1.03	-0.91	-0.72	-0.68
	0.0008	0.0008	-0.0000	-0.0000	-0.0005	-0.0004	-0.0001	-0.0001	0.0006	0.0002	-0.0002	-0.0002
Trading Volume	*0.0004*	*0.0004*	*0.0001*	*0.0001*	*0.0002*	*0.0002*	*0.0001*	*0.0001*	*0.0020*	*0.0018*	*0.0005*	*0.0005*
	2.09	2.30	-0.35	-0.42	-2.69	-2.29	-1.03	-1.04	0.29	0.08	-0.32	-0.35
		-0.0284		0.0031		-0.0770		-0.0008		0.2950		0.0141
Speculators(MS)		*0.0406*		*0.0040*		*0.0236*		*0.0033*		*0.1527*		*0.0243*
		-0.70		0.77		-3.27		-0.23		1.93		0.58
			0.9772	0.9777			0.9533	0.9524			0.9602	0.9570
Lagged Volatility			*0.0122*	*0.0124*			*0.0127*	*0.0149*			*0.0199*	*0.0218*
			80.00	78.84			74.86	64.05			48.30	43.83
Adj. R2 %	1.13	1.39	95.38	95.38	8.35	16.05	91.36	91.35	16.72	21.95	95.02	95.01

Table 3.15 WTI Crude Oil 18-Month Maturity Futures Volatility Forecast

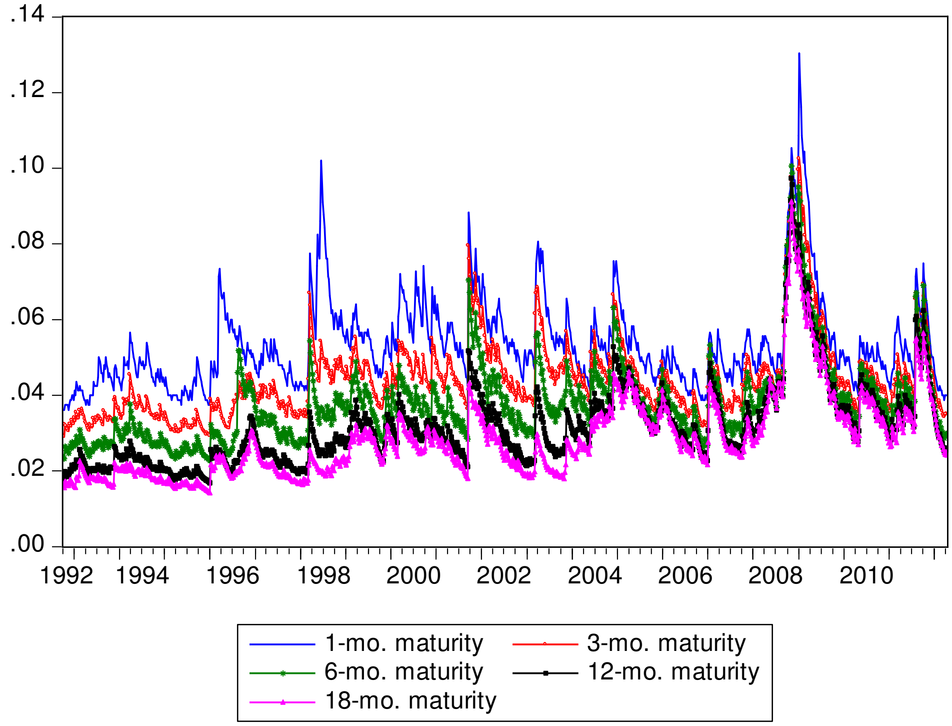
This table is created the same way as Table 3.6 using 18-month maturity WTI crude oil futures. The numbers in italic are HAC (Newey-West) (Heteroscedasticity and Autocorrelation Consistent) standard errors and underlined numbers are t-statistics.

	Panel (a): Full Period				**Panel (b): Pre-crisis Period**				**Panel (c): Post-crisis Period**			
Predictor Variable	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)	(1)	(2)	(3)	(4)
	0.0309	0.0309	0.0005	0.0005	0.0257	0.0257	0.0004	0.0005	0.0496	0.0459	0.0016	0.0016
c	*0.0011*	*0.0011*	*0.0003*	*0.0004*	*0.0008*	*0.0007*	*0.0004*	*0.0005*	*0.0053*	*0.0042*	*0.0010*	*0.0010*
	28.81	29.26	1.56	1.51	32.29	35.12	1.12	0.96	9.40	10.92	1.60	1.68
	0.0465	0.0593	-0.0007	-0.0004	-0.0387	0.0006	-0.0013	-0.0009	-0.1973	-0.1942	-0.0089	-0.0088
Inventory	*0.0161*	*0.0254*	*0.0019*	*0.0026*	*0.0120*	*0.0161*	*0.0022*	*0.0018*	*0.0980*	*0.0945*	*0.0108*	*0.0110*
	2.89	2.33	-0.38	-0.16	-3.23	0.04	-0.61	-0.48	-2.01	-2.05	-0.82	-0.80
	-0.0016	-0.0016	-0.0001	-0.0001	-0.0008	-0.0007	-0.0000	-0.0000	0.0047	0.0040	-0.0002	-0.0002
Open Interest	*0.0006*	*0.0006*	*0.0001*	*0.0001*	*0.0004*	*0.0004*	*0.0001*	*0.0001*	*0.0024*	*0.0021*	*0.0003*	*0.0003*
	-2.70	-2.72	-1.51	-1.52	-1.83	-1.92	-0.88	-0.87	1.95	1.89	-0.70	-0.66
	-0.0001	-0.0001	0.0001	0.0001	0.0006	0.0005	0.0001	0.0001	-0.0031	-0.0027	0.0000	0.0000
Trading Volume	*0.0004*	*0.0004*	*0.0000*	*0.0000*	*0.0003*	*0.0003*	*0.0000*	*0.0000*	*0.0011*	*0.0010*	*0.0001*	*0.0001*
	-0.21	-0.31	1.48	1.50	1.95	1.59	1.78	1.80	-2.90	-2.80	0.22	0.18
		-0.0314		-0.0008		-0.0870		-0.0011		0.1987		-0.0038
Speculators(MS)		*0.0442*		*0.0039*		*0.0262*		*0.0041*		*0.1570*		*0.0179*
		-0.71		-0.20		-3.32		-0.26		1.27		-0.21
			0.9819	0.9818			0.9831	0.9818			0.9667	0.9674
Lagged Volatility			*0.0116*	*0.0120*			*0.0142*	*0.0177*			*0.0212*	*0.0212*
			84.55	81.97			69.19	55.37			45.68	45.69
Adj. R2 %	5.62	5.84	96.72	96.71	5.79	15.19	93.90	93.89	16.86	19.35	95.60	95.57

Figure 3.1 Volatility of WTI Crude Oil Futures Curves

This figure presents the weekly volatility of WTI Crude Oil futures curves with constant maturities. The volatility in graph (a) is estimated by a GARCH (1, 1) model given in equation (3.3) and (3.4) while the volatility presented in graph (b) is estimated using Parkinson (1980) High-Low volatility estimator given in equation (3.7). The sample period covers data from October 1992 to May 2012.

(a)



(b)

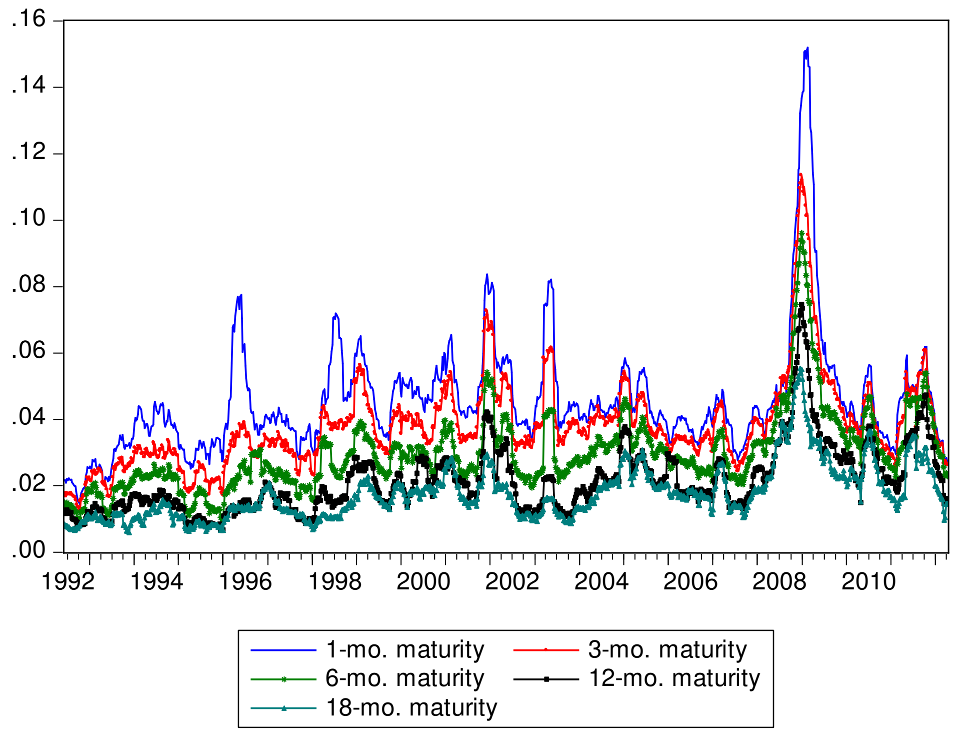


Figure 3.2 Speculators in WTI Crude oil Futures Market

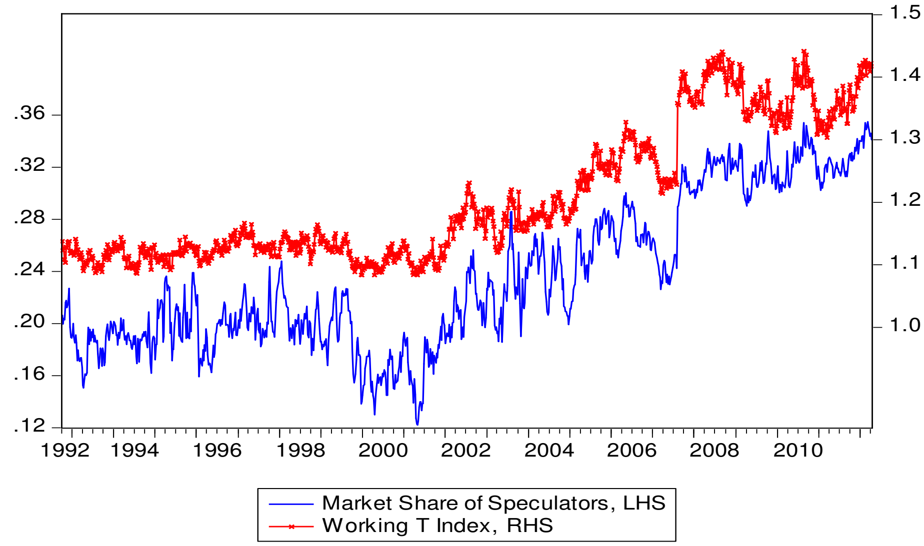
This figure shows two different measurements of speculators (non-commercial traders) positions in WTI crude oil futures market. The left hand side of the figure presents the market share of speculators calculated by the model; $\frac{SL+SS}{2*OI}$,where SL and SS are the number of long positions and short positions of speculators respectively, and OI is the total open interest in this market. The right hand side of the graph presents Working T index, which is a measurement of excess speculation in the market and calculated by the model;

$$T = 1 + \frac{SS}{HS + HL} \ if \ HS \geq HL,$$

$$T = 1 + \frac{SL}{HS + HL} \ if \ HS \leq HL$$

Here, SL and SS are same as above, and HL and HS are the number of long positions and short positions of speculators, respectively. The second graph presents the detrended time series that are used in our research.

(a)



(b)

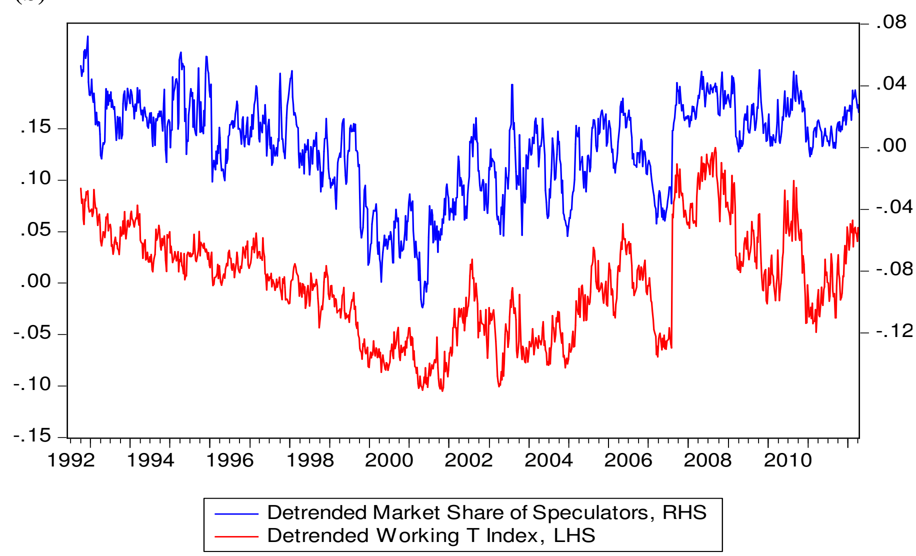
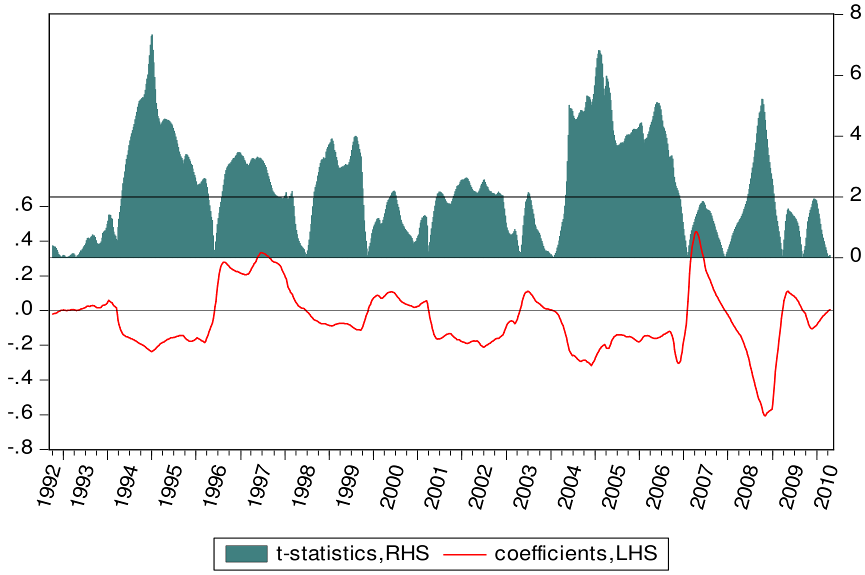


Figure 3.3 Rolling Regression with Inventory

This figure represents the rolling regression results between volatility of WTI crude oil futures and inventory. The upper panel shows the regression result between 1-month maturity volatility and inventory while the lower panel represents result between 18-month maturity volatility and inventory. A two years calibration period is used in regressions. The shaded area gives the absolute t-statistics calculated by HAC (Newey-West) (heteroscedasticity and autocorrelation consistent) standard errors of the coefficients.



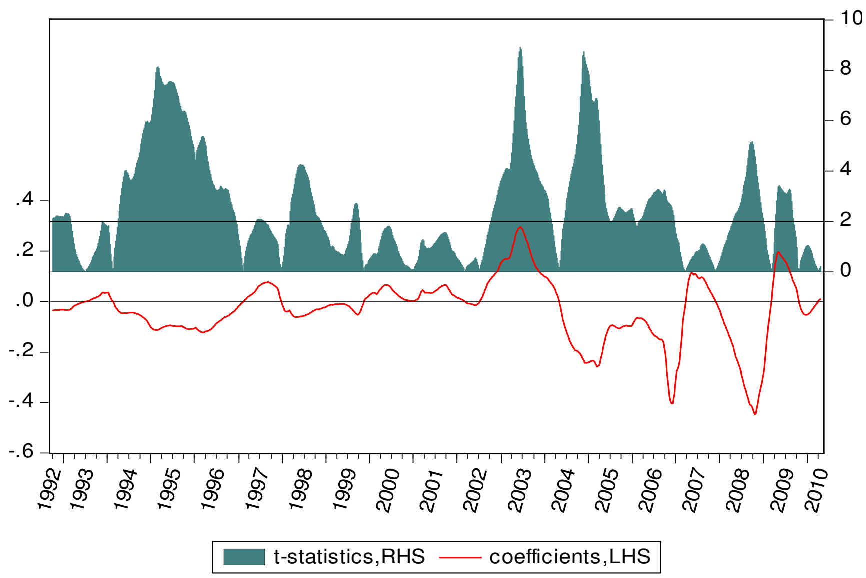


Figure 3.4 Recursive Regressions with Inventory

This figure represents the recursive regression results between volatility of WTI crude oil futures and inventory. The upper panel shows the regression result between 1-month maturity volatility and inventory while the lower panel represents result between 18-month maturity volatility and inventory. A two years calibration period is used in regressions. The shaded area gives the absolute t-statistics calculated by HAC (Newey-West) (heteroscedasticity and autocorrelation consistent) standard errors of the coefficients.

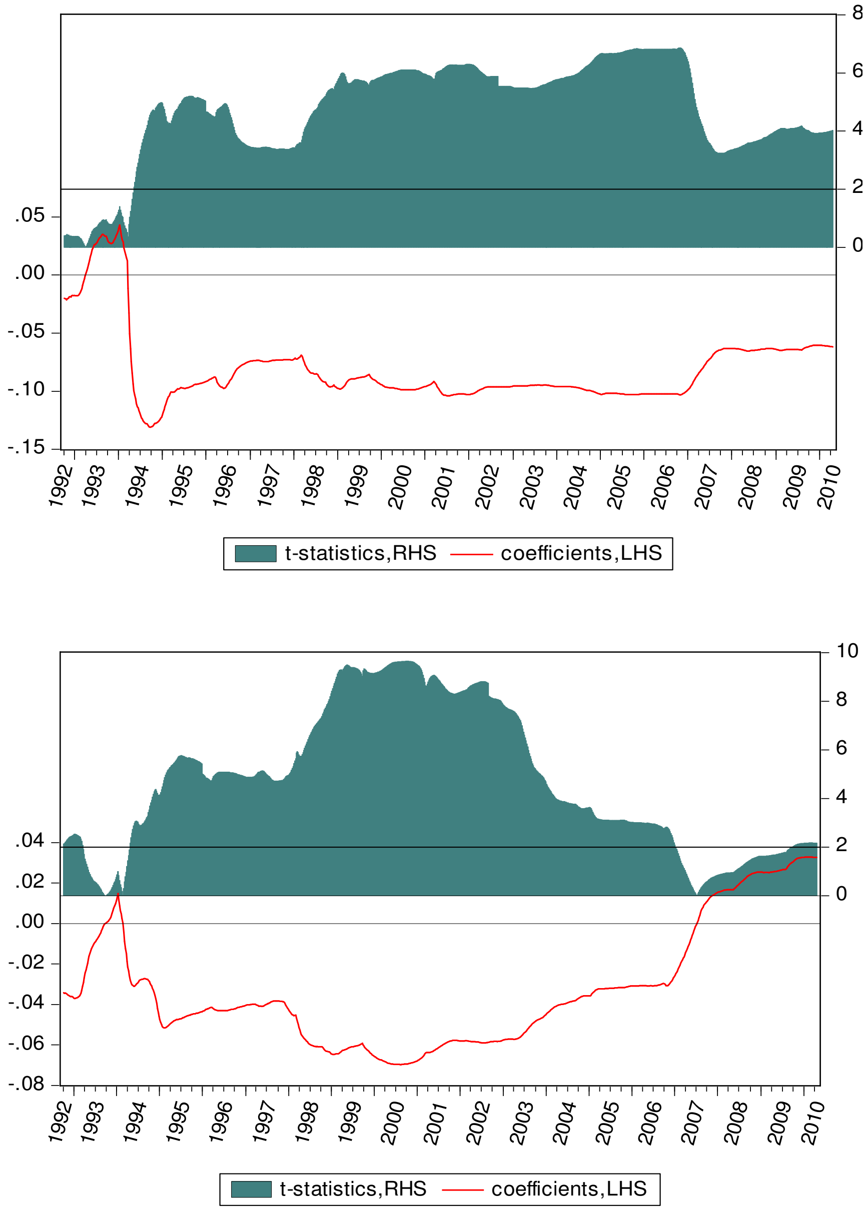
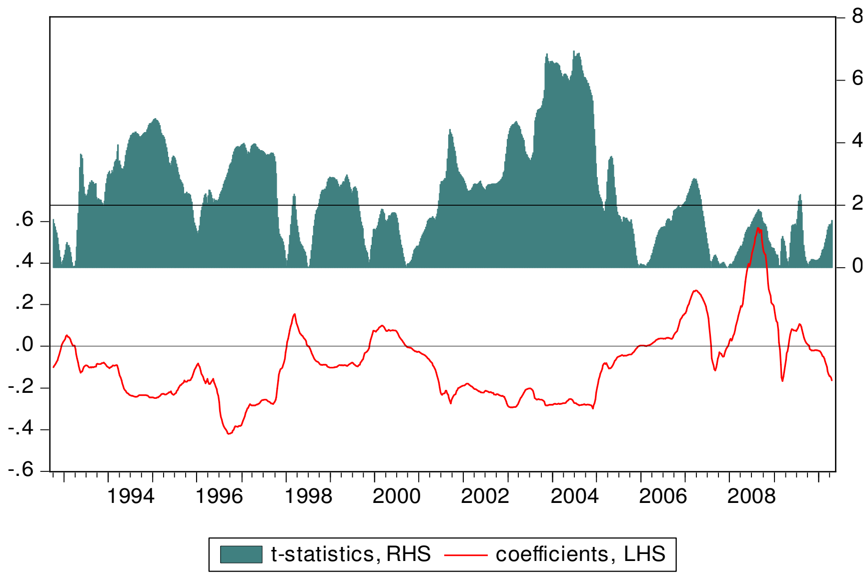


Figure 3.5 Rolling Regression with Market Share of Speculators

This figure represents the rolling regression results between volatility of WTI crude oil futures and market share of speculators. The upper panel shows the regression result between 1-month maturity volatility and market share of speculators while the lower panel represents result between 18-month maturity volatility and market share of speculators. A two years calibration period is used in regressions. The shaded area gives the absolute t-statistics calculated by HAC (Newey-West) (heteroscedasticity and autocorrelation consistent) standard errors of the coefficients.



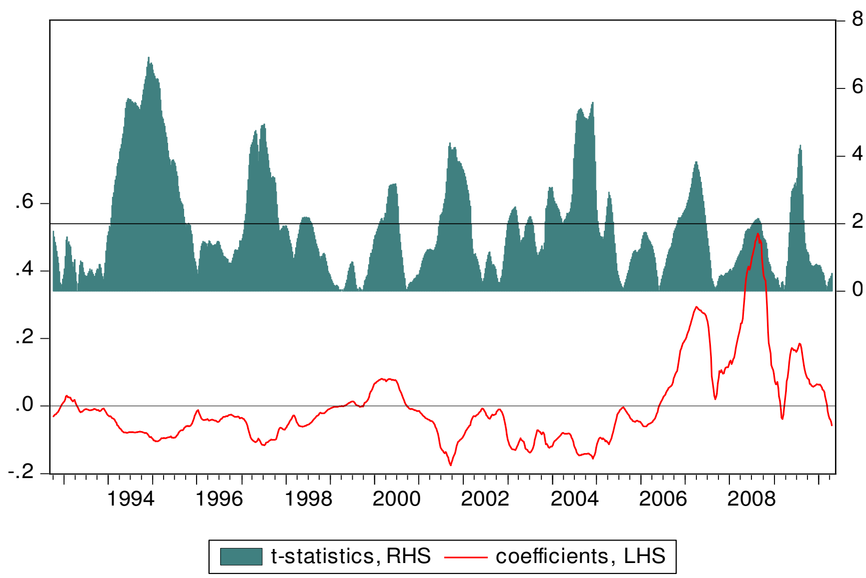
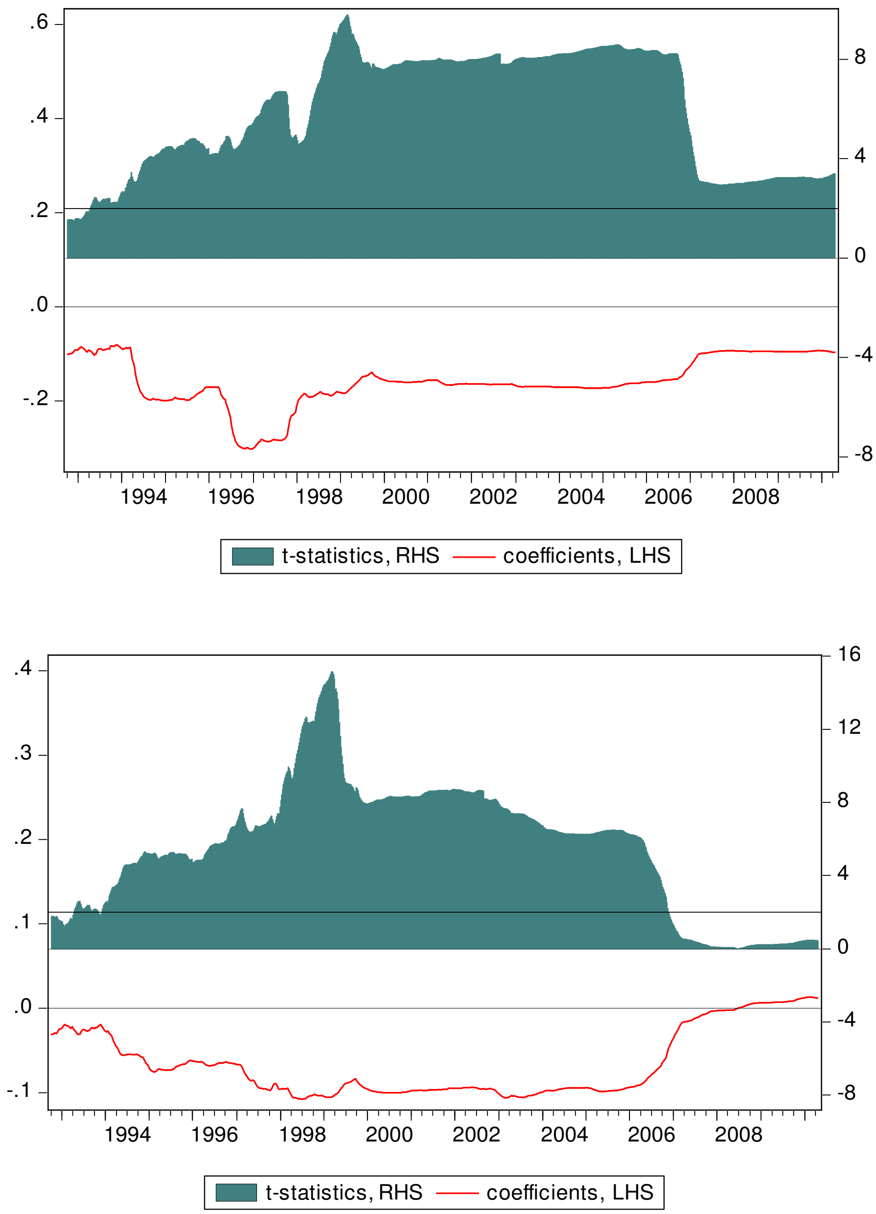


Figure 3.6 Recursive Regressions with Market Share of Speculators

This figure represents the recursive regression results between volatility of WTI crude oil futures and market share of speculators. The upper panel shows the regression result between 1-month maturity volatility and market share of speculators while the lower panel represents result between 18-month maturity volatility and market share of speculators. A two years calibration period is used in regressions. The shaded area gives the absolute t-statistics calculated by HAC (Newey-West) (heteroscedasticity and autocorrelation consistent) standard errors of the coefficients.



Conclusion

The Efficient Market Hypothesis of Fama (1970) implies that futures price is an unbiased estimator of future spot prices and past price information cannot not be used to predict future spot prices. Considering the fact that the success of hedging and price discovery in futures markets depends on how efficient markets are, we revisit this hypothesis from a different perspective in the first research chapter. We analyse the market efficiency in metal, agricultural, financial and energy markets using contracts with up to 8-month maturities following the argument of Kawamoto and Hamori (2011) that a long-maturity futures prices can be seen as the market expectation of a short-maturity futures price. We are the first study to examine the market efficiency both in the long-run and in the short run across different maturity futures in metal, agricultural and financial markets as well as to use a relative degree of inefficiency methodology developed by Kellard et al. (1999). First of all, we found that all the futures markets studied are efficient in the long-run along the futures curve in the sense that the hypothesis of existence of a [1, -1] cointegrating vector cannot be rejected in any of the markets for any of the maturities. However, in the short-run, we observed inefficiencies in all of the markets studied except the live cattle and USD/GBP exchange rate markets. Secondly, the results regarding the degree of efficiency gives some interesting insights about these markets. It is found that all markets studied are around 90% efficient across up to 8-month maturities from a 30-day forecast horizon period. However, when we increase the forecast horizon to 60 days, efficiency in all metal and WTI Crude Oil futures drops to 50%. But this is not the case in Live Cattle or USD/GBP markets which are still more than 90% efficient along yield curve maturities. Further analysis reveals that the sharp drop in efficiency in the metal and WTI Crude Oil futures markets comes from the inability of long-maturity futures price to predict short-maturity futures price from a 60-day horizon. This suggests that the forecast horizon and the structure of the markets studied have vital importance in market efficiency analysis.

The second chapter examines the diversification benefits brought into traditional stocks portfolio by adding commodity futures contracts. Geman and Khaorubi (2008) analyse the impact of the choice of the futures contracts on portfolio enhancement and argue that distant maturity WTI Crude Oil futures contracts provides better diversification. However, many studies found that the correlation between returns of commodities and equities increased sharply especially after the 2008 financial crisis (Buyuksahin and Robe, 2014; Delatte and Lopez, 2013; Li and Zhang 2013; Bhardwaj and Dunsby, 2012; Silvennoinen and Thorp, 2013; Bicchetti and Maystre, 2012). This development in commodity futures markets raises a question of what happened to diversification benefits, if there were any, after the so called financialization. We revisit this issue using Copper, Aluminium and WTI Crude Oil constant maturity futures contracts and a dynamic conditional correlation model. Our results first confirm that the correlation between return of commodities and equities have increased dramatically after the 2008 financial crisis. However, it seems that this increasing trend started as early as in 2000s which is consistent with the claim of Tang and Xiong (2012) that financialization started in early 2000s. Our main contributions with regard to portfolio construction are three-fold. First, our results suggest that investors can still enjoy benefits of using certain commodity futures contracts in portfolio diversification even after the financial crisis. However the commodity needs to be carefully selected. For example, we found that including WTI Crude Oil futures contracts in the portfolio no longer benefits in the post-crisis period while including Copper and Soya Bean futures still provide the diversification benefits. Second, we found that an investor would be better off using distant-constant maturity futures contract in comparison to a short-maturity one. This is the case for all commodities in the pre-crisis period. However, in the post-crisis period, only Copper futures contract supports this difference in distant- and short-maturity contracts. Further analyses suggests that the advantage of using distant-maturity futures contracts over their short-maturity conterparts comes from their higher return and lower risk. This is different from Geman and Khaorubi (2008) who suggest it is the difference in the dependence structure of distant- and short-maturity futures with equities leads to the difference in their diversification benefits. Finally, our results suggest holding a distant-constant maturity futures contracts provides a larger diversification benefit when compared with the traditional long and hold a distant-maturity futures contracts.

The determinants of volatility along WTI Crude Oil futures curves are examined in the third research chapter of this thesis. Understanding volatility in commodity futures contracts is vital to many market participants from hedgers to futures contract traders. Many studies have analysed the determinant of volatilities in commodity futures markets following different hypothesis. Some of the hypotheses include: 1) Samuelson hypothesis which suggests that volatility in futures contracts increases with maturity (Samuelson, 1965), 2) the theory of storage which suggests that volatility and inventory has a negative relationship (Kaldor, 1939; Working, 1948, 1949), 3) trading volume and volatility has a positive relationship, while open interest and volatility has a negative one (Ripple and Moosa, 2009), and 4) Masters Hypothesis which suggests that speculative activities distorted commodity futures prices hence caused higher volatility in these markets (Masters, 2008, 2009). We revisit all these hypotheses and study their effect on constant maturity WTI Crude Oil futures contracts. Our findings suggest that trading volume and open interest has the expected effect on the volatility of constant maturity futures contracts. However, the results from inventory and speculative activities are quite intriguing. Firstly, we found that while the coefficient of inventory and the volatility of up to 6-month maturity futures have a negative relationship as indicated in the theory, this relationship becomes positive in 12 and 18-month maturities. Moreover, the coefficient of inventory in 18-month maturity being almost as high as in 1-month maturity with an opposite sing and significant suggests that scarcity (high inventory) would increase (decrease) volatility in shorter maturities while it decreases (increases) it in longer maturities. Secondly, we found that speculative activities have exacerbated the high volatility in post-crisis period.

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